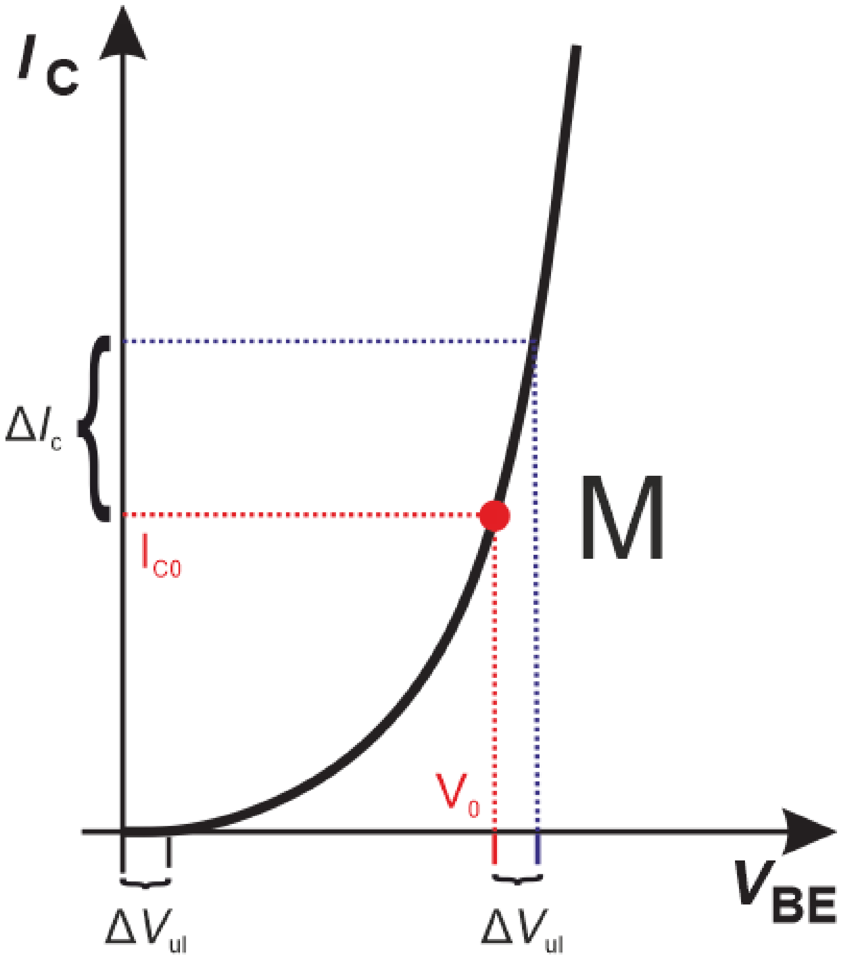
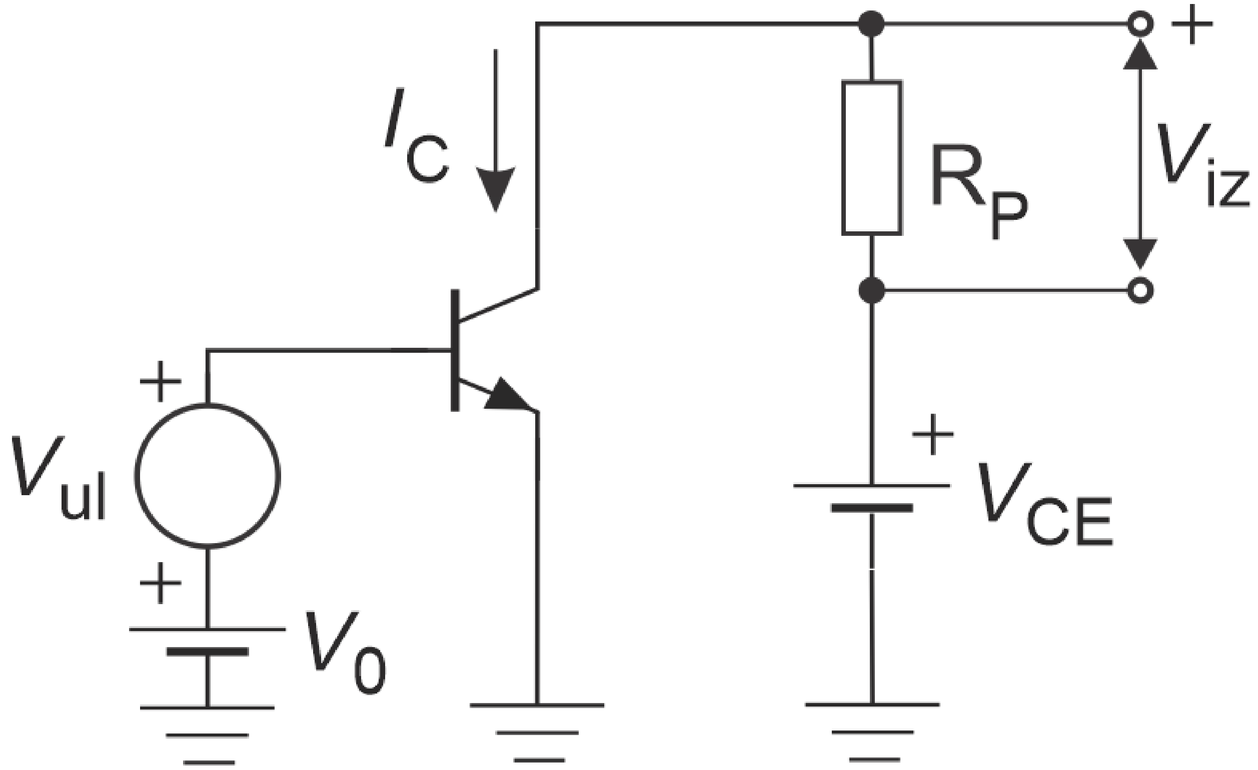
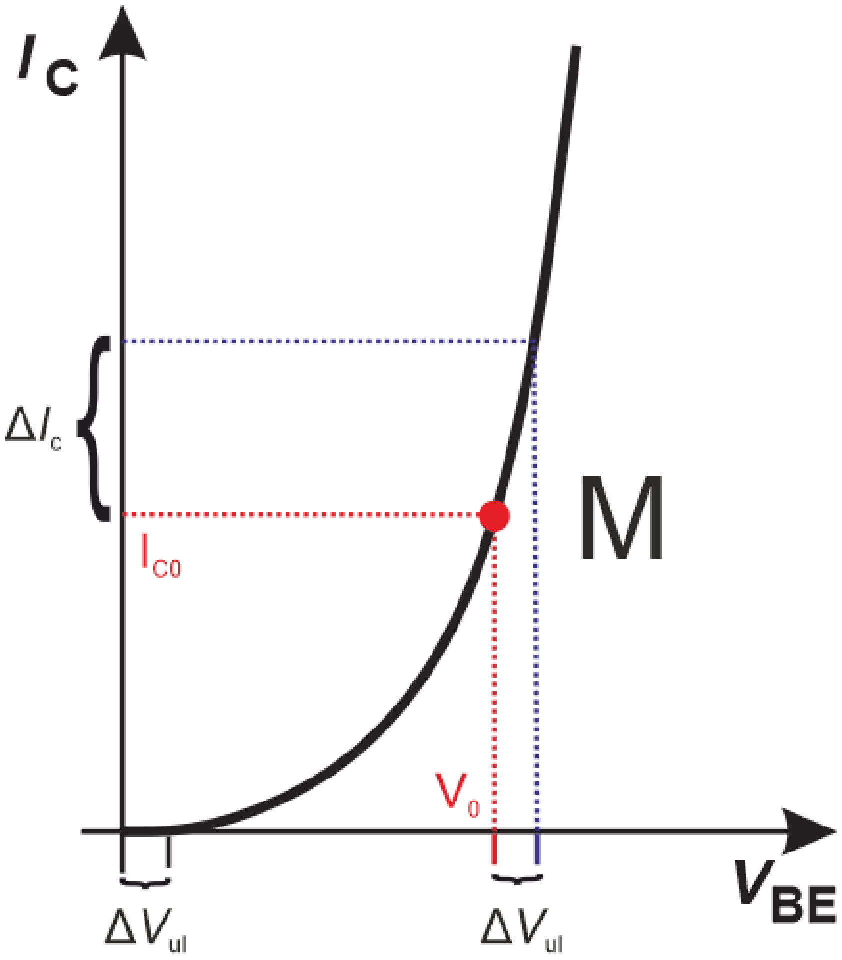
Bipolarni tranzistor
Modeli tranzistora, Erlijev efekat,
PNP tranzistor

Polarizacija i radna tačka



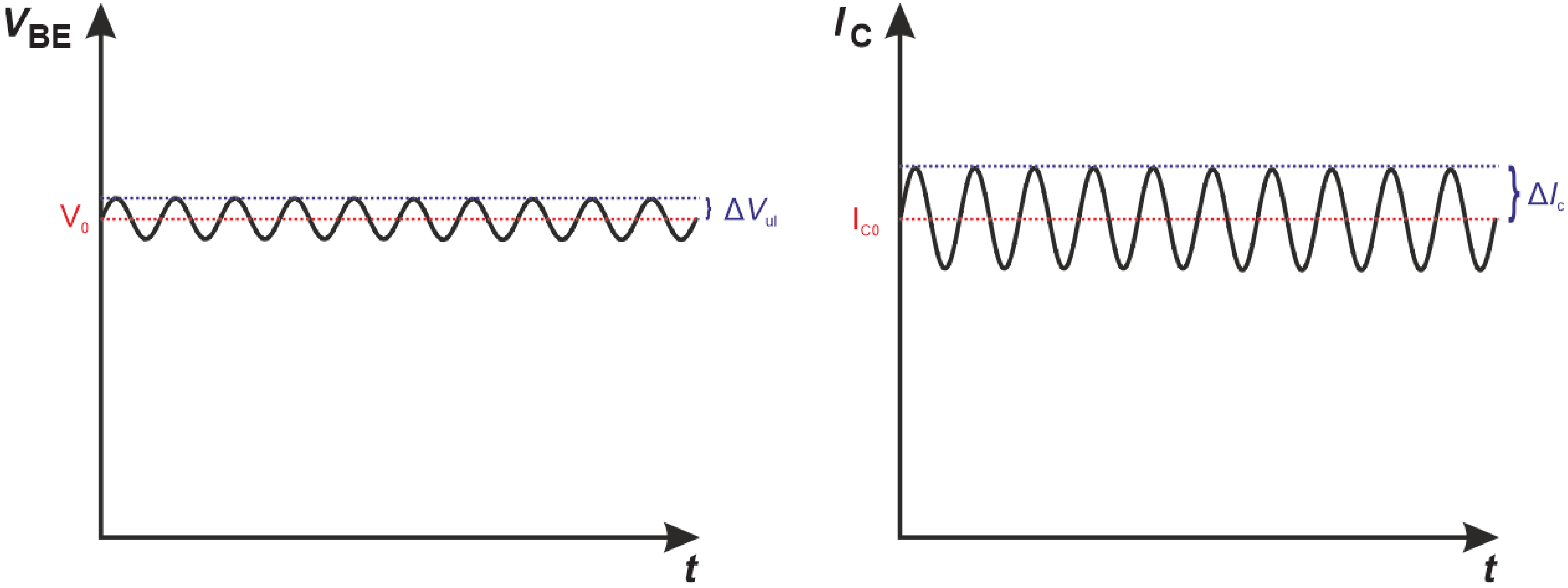


Polarizacija i radna tačka

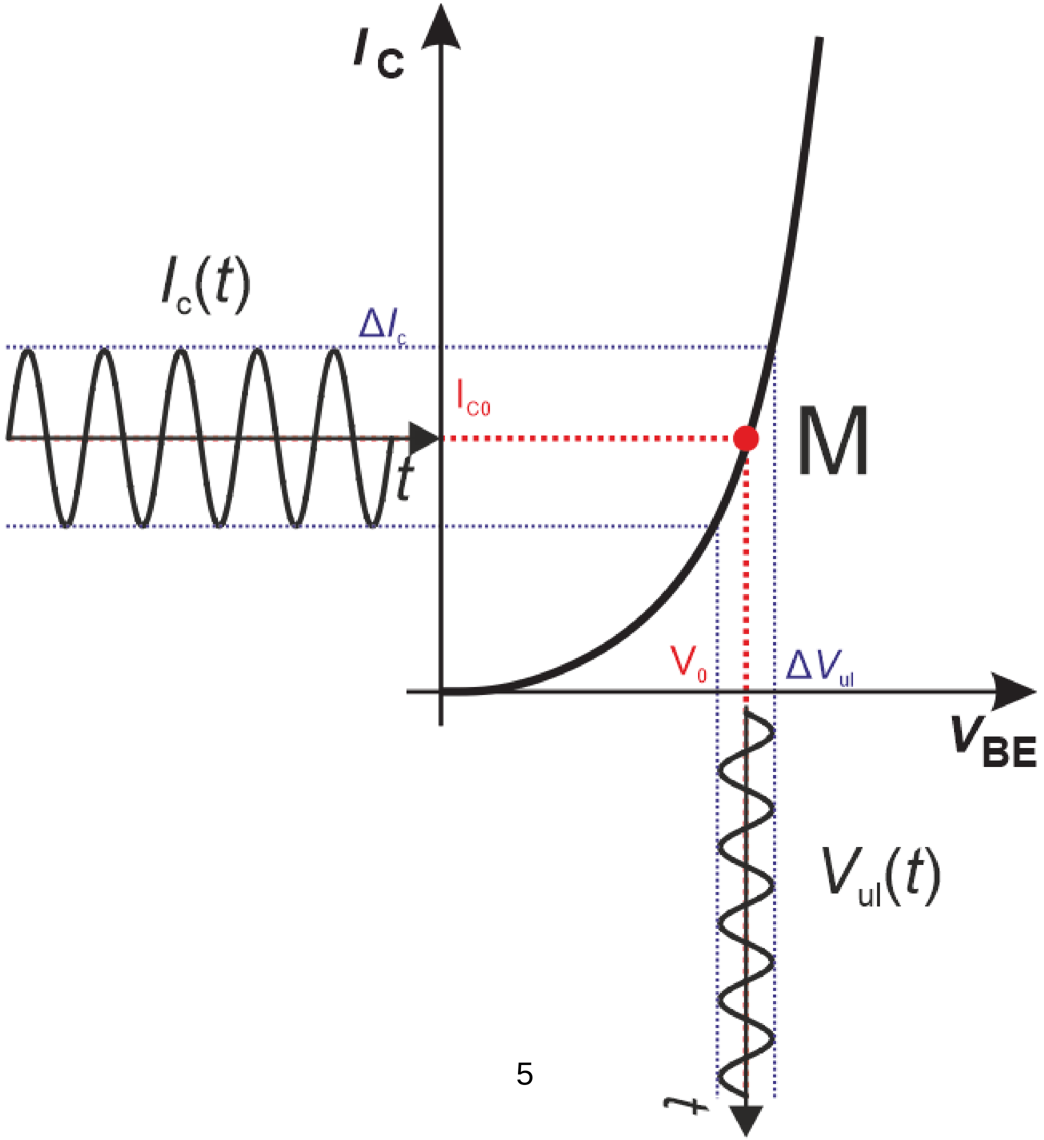


- Polarizacijom bipolarnog tranzistora određujemo radnu tačku, tačku na prenosnoj karakteristici u kojoj mala promena napona na emitroskom spoju dovodi do velike promene struje kolektora.
- Radna tačka tranzistora određena je jednosmernim naponima polarizacije V_{BE}, V_{CE} i struje I_C.

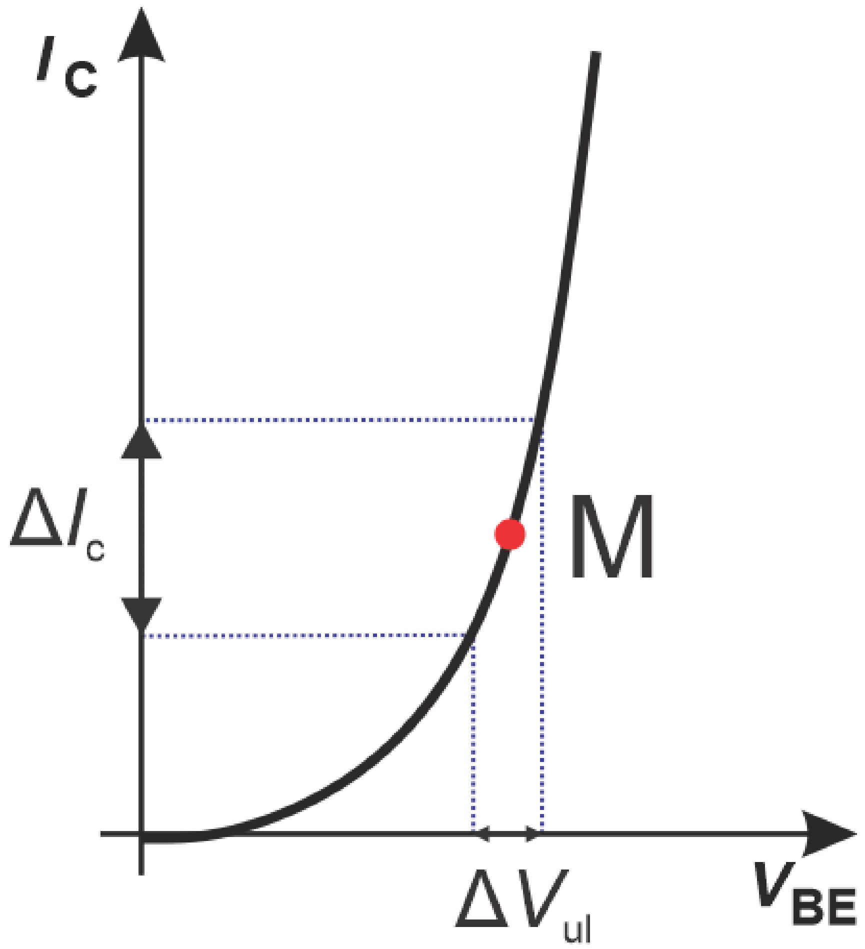
Polarizacija i radna tačka



Polarizacija i radna tačka



Transkonduktansa



$$I_C = I_S \cdot \left(\exp\left(\frac{V_{BE}}{V_T} \right) - 1 \right)$$

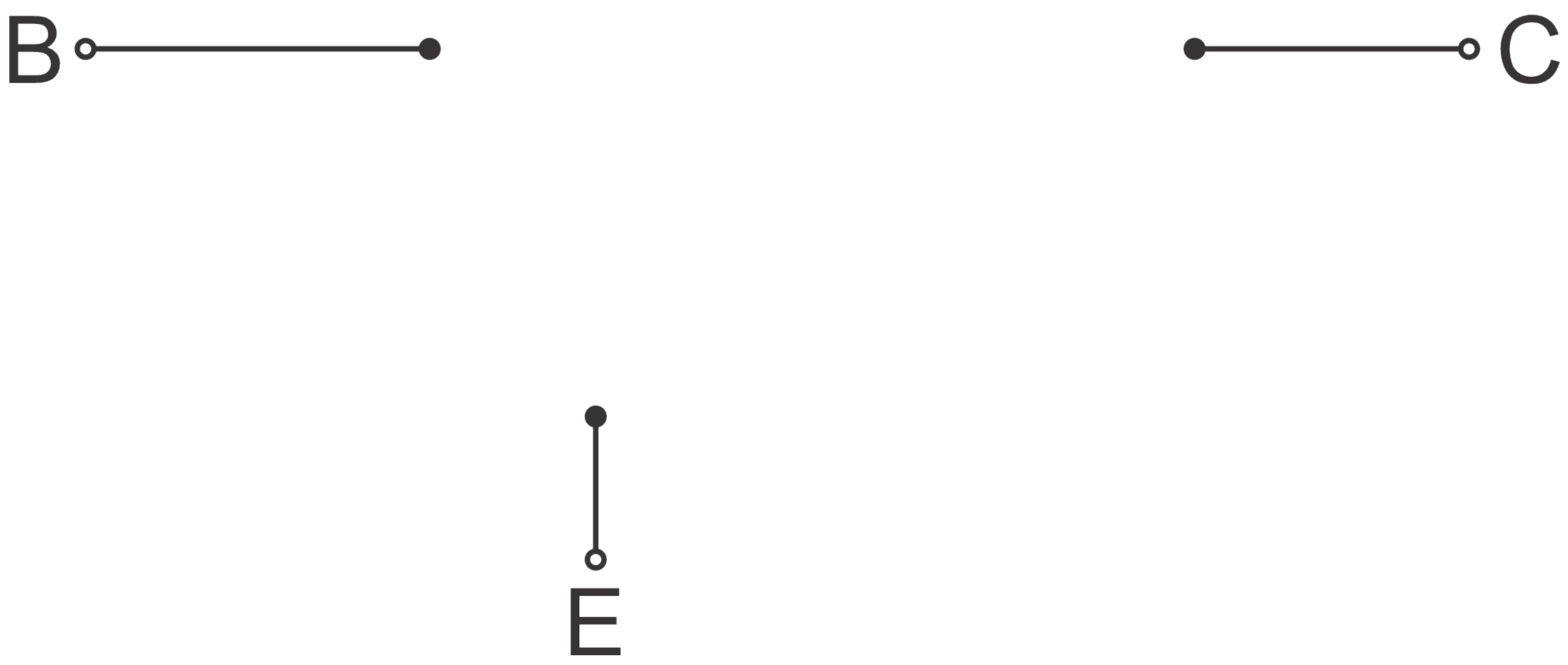
$$g_m = \frac{dI_C}{dV_{BE}}$$

$$g_m = \frac{I_S}{V_T} \cdot \exp\left(\frac{V_{BE}}{V_T} \right) = \frac{I_C}{V_T}$$

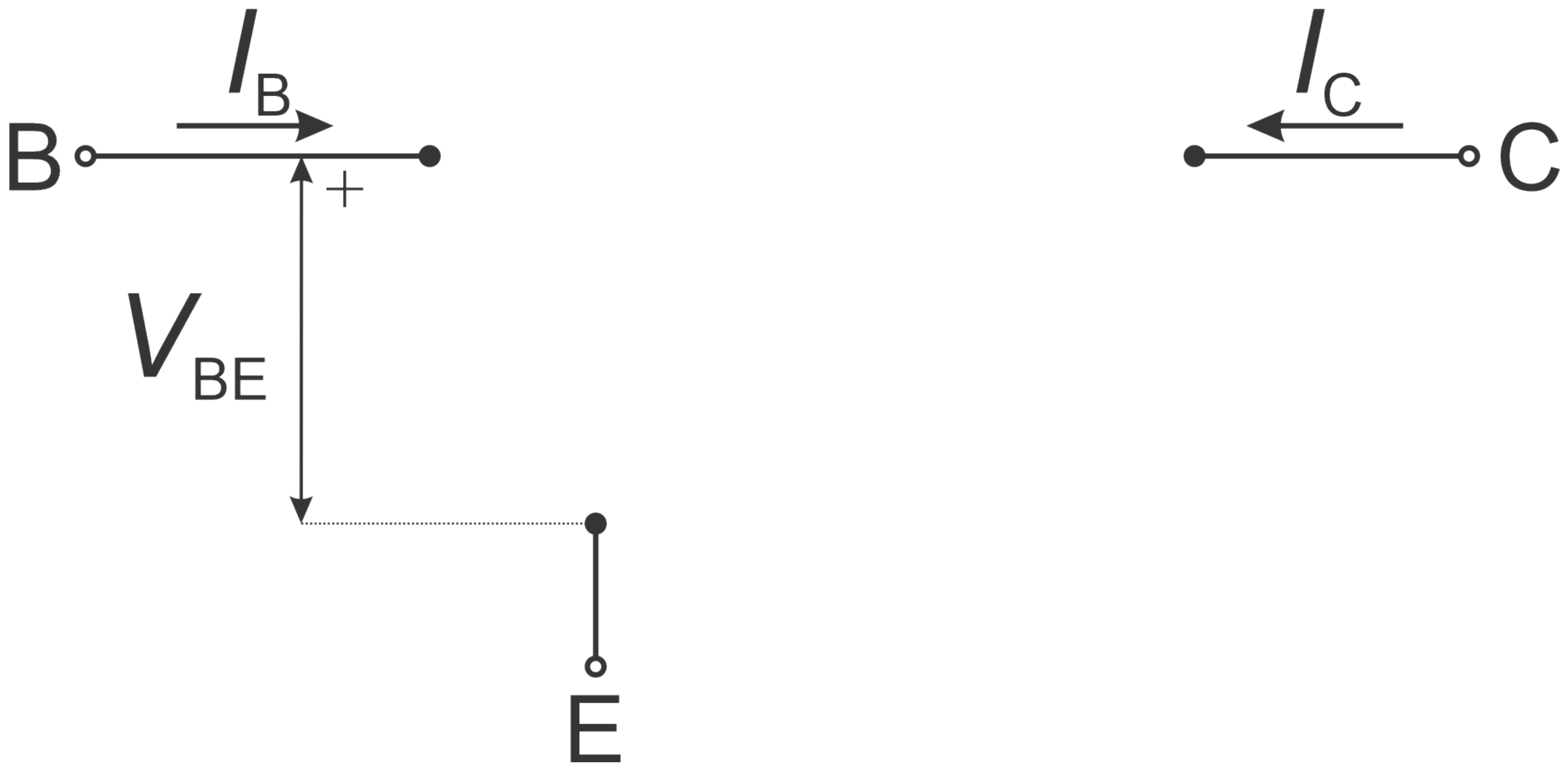
Transkonduktansa

- Transkonduktansa zavisi od radne tačke tranzistora.
- Pojačanje je proporcionalno transkonduktansi.
- Transkonduktansa je proporcionalna struji kolektora, veća transkonduktansa (samim tim i pojačanje) zahteva veću snagu generatora koji napaja kolo.

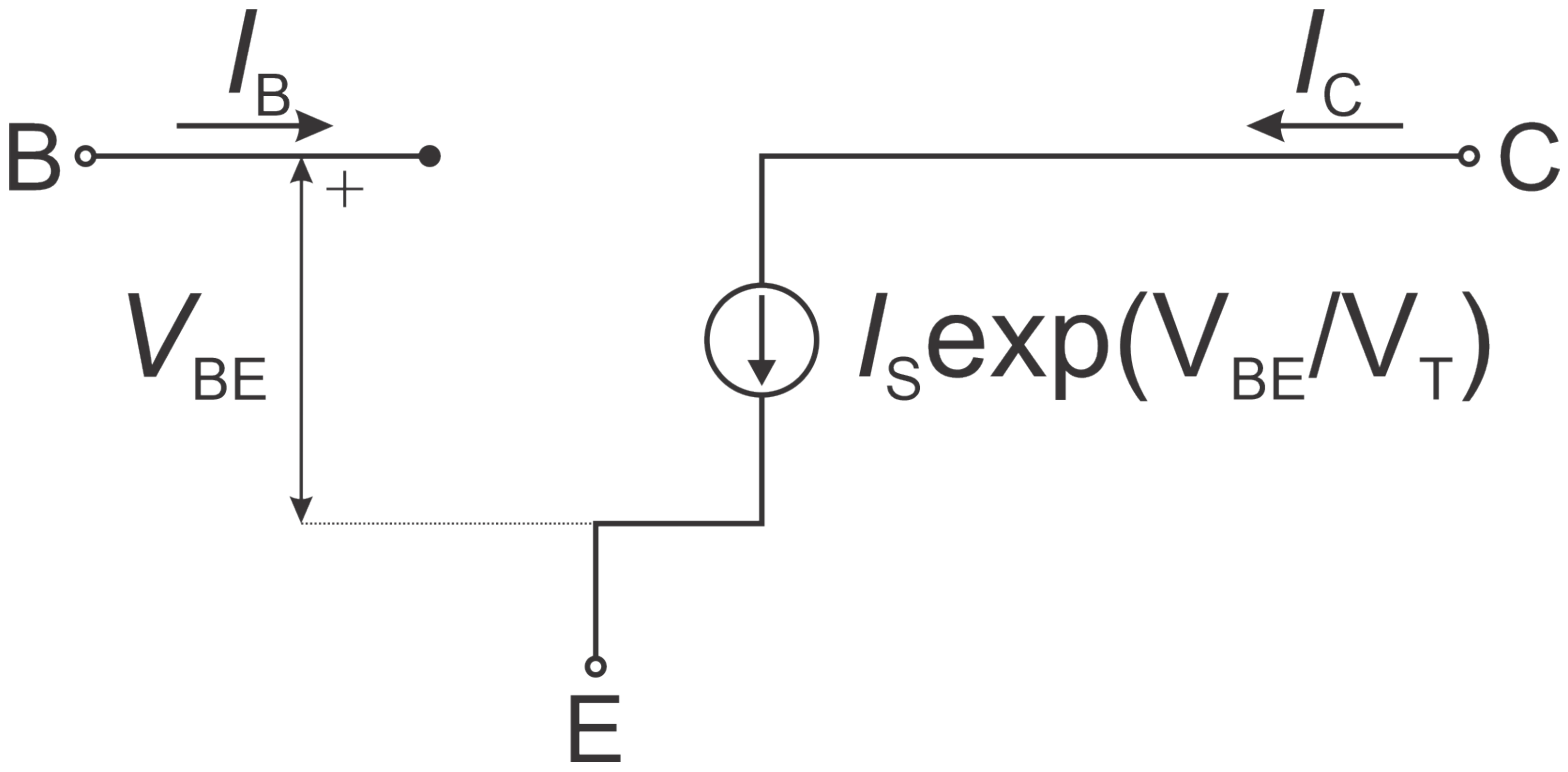
Jednostavni model bipolarnog tranzistora



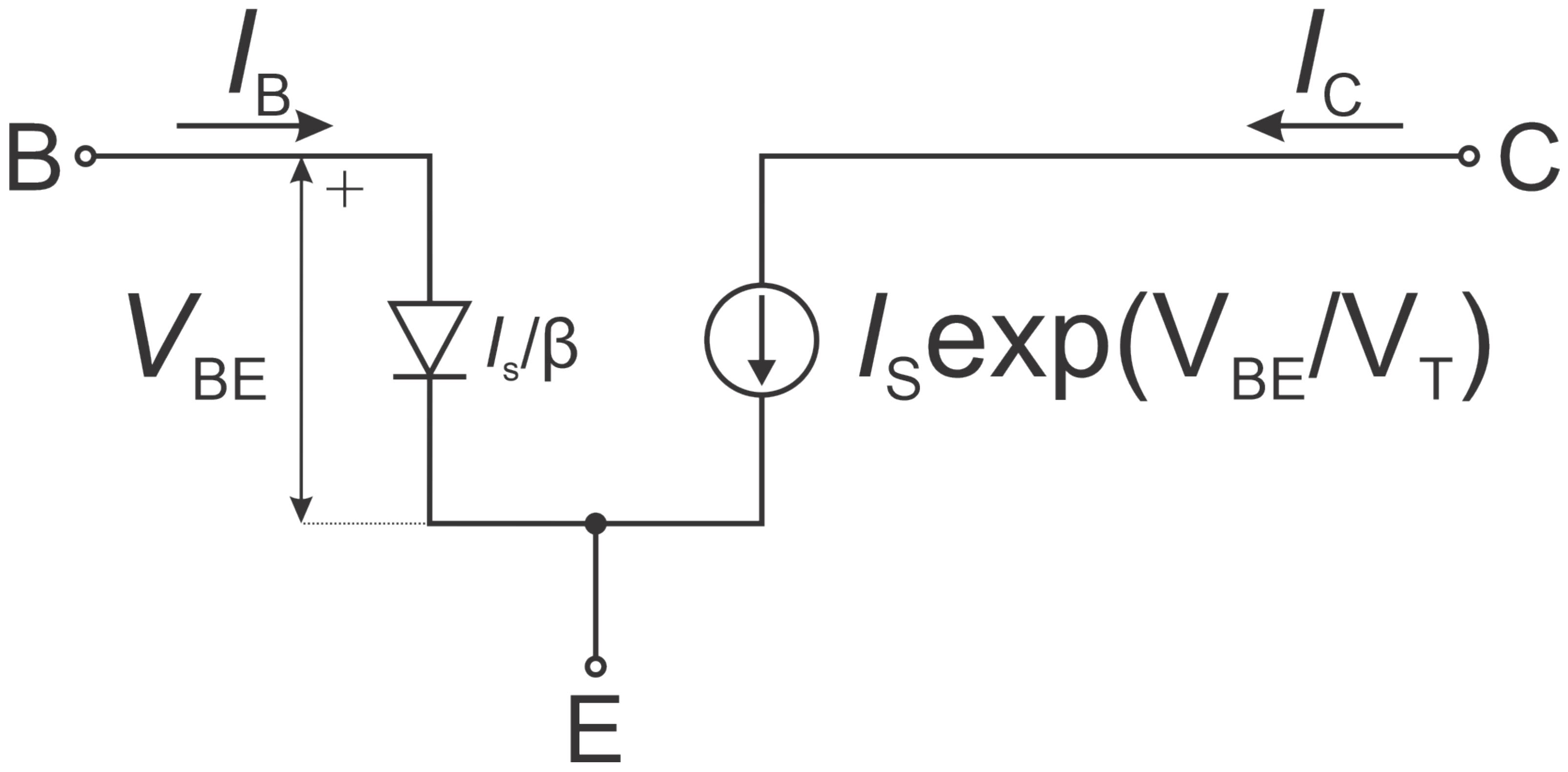
Jednostavni model bipolarnog tranzistora



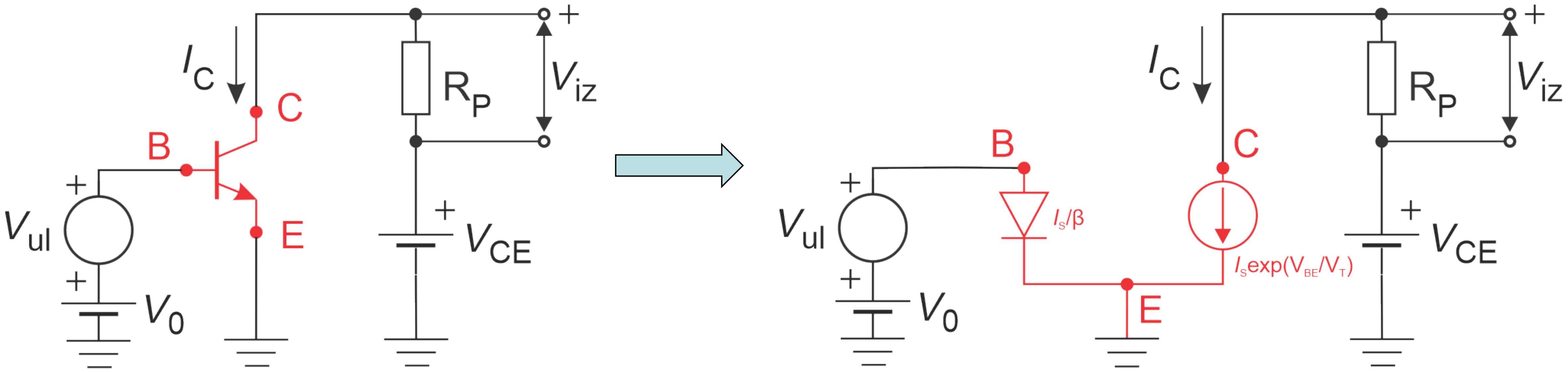
Jednostavni model bipolarnog tranzistora



Jednostavni model bipolarnog tranzistora



Jednostavni model bipolarnog tranzistora



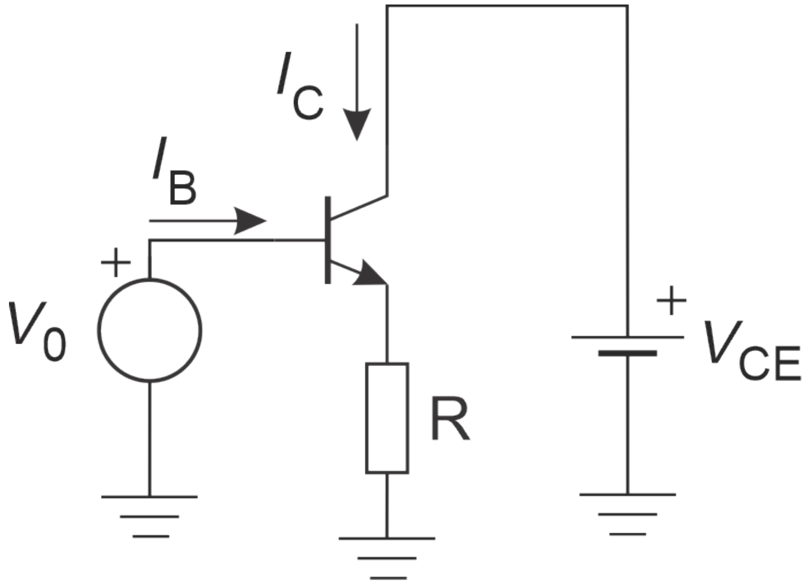
Model bipolarnog tranzistora za velike signale

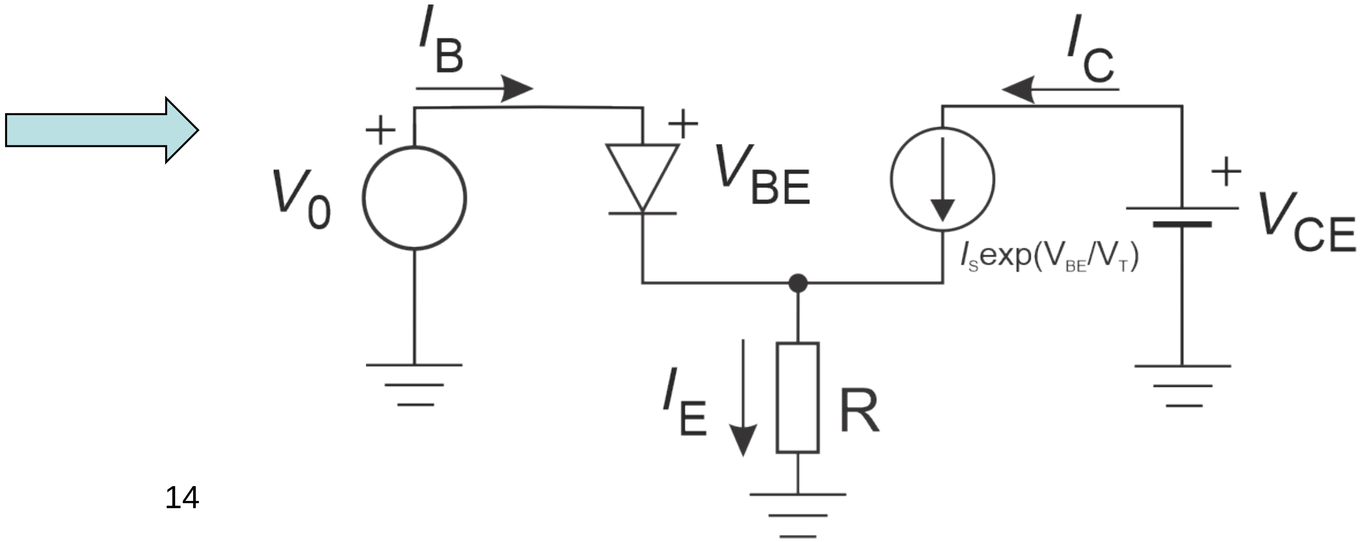
- Model je ispravan samo ako je tranzistor u aktivnoj oblasti (emitorski spoj direktno polarisan, kolektorski inverzno polarisan).
- Ovaj model se zove **model bipolarnog tranzistora za velike signale.**
- Signal Vul može biti proizvoljan
- Model je nelinearan.

Primer

$$I_S = 10^{-16}\,\mathrm{A},\ \ \beta = 100$$

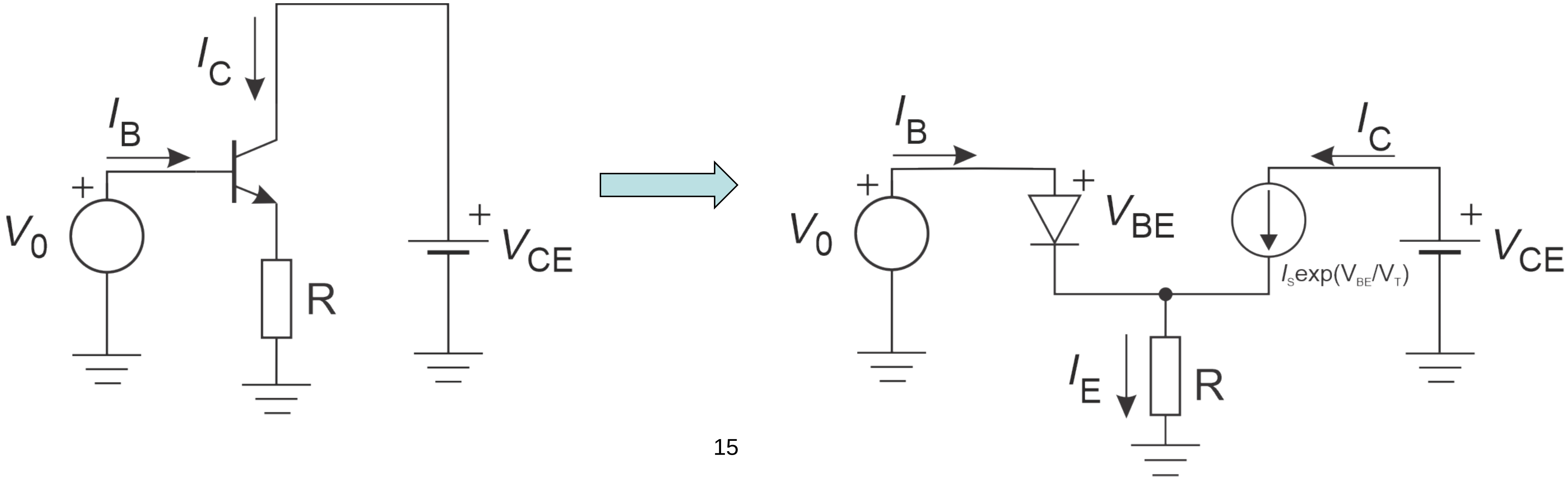
$$I_C \approx I_E,\ R = 100\Omega,\ V_{ul} = V_0 = 800\mathrm{mV},\ V_{CE} = 3\mathrm{V}$$





Primer

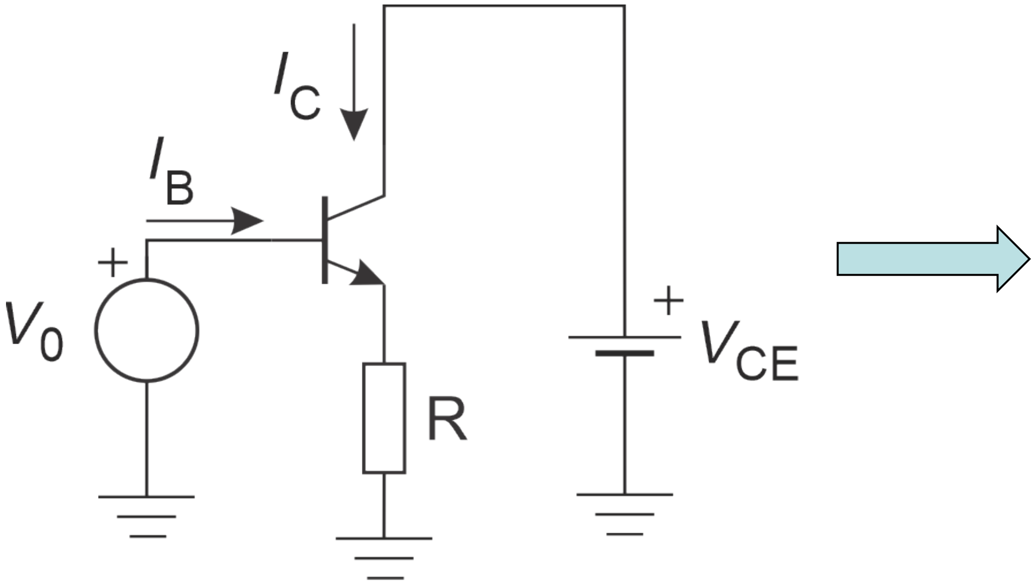
$$V_0 = V_{\mathrm{BE}} + I_{\mathrm{E}} \cdot R \approx V_{\mathrm{BE}} + I_{\mathrm{C}} \cdot R$$

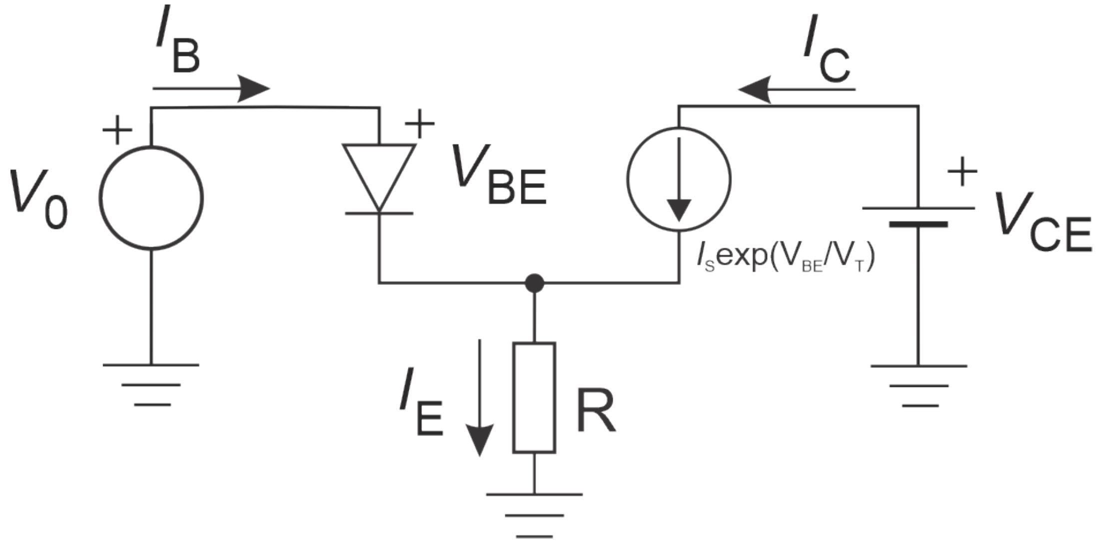


Primer

$$V_{BE} = V_T \cdot \ln\left(\frac{I_C}{I_S}\right)$$

$$V_0 = V_T \cdot \ln\left(\frac{I_C}{I_S}\right) + I_C \cdot R$$

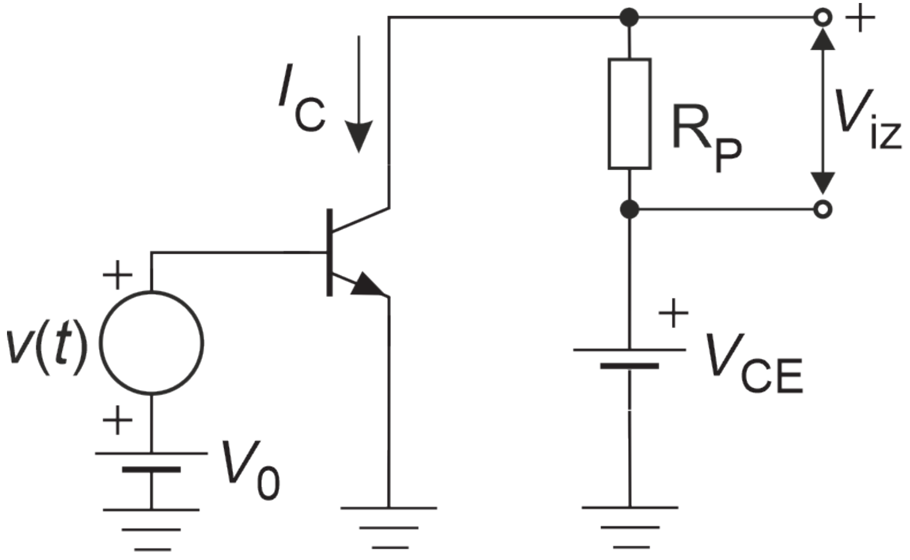


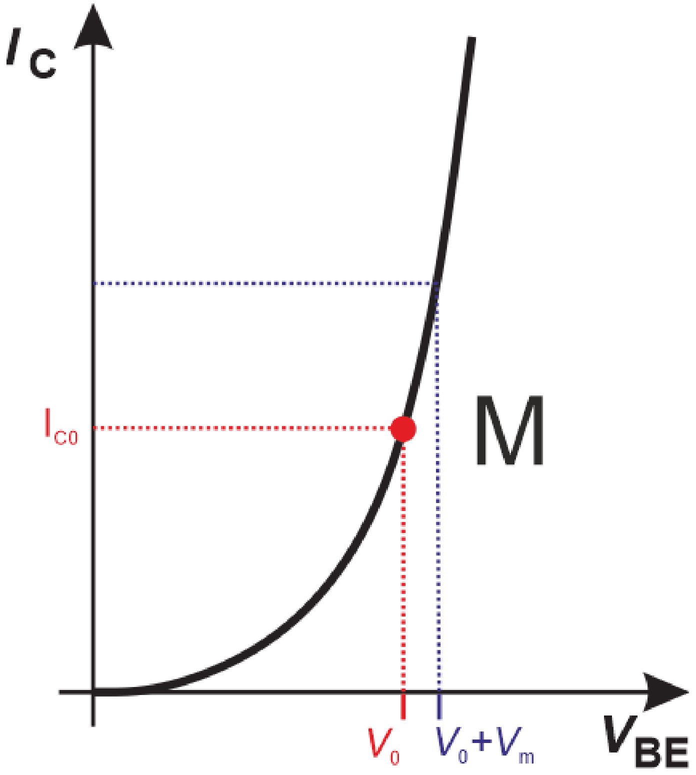


Model bipolarnog tranzistora za male signale

- Signal $v(t)$ je superponiran jednosmernom naponu V_0, promena napona V_{BE} je mala ($V_m \ll V_0$):

$$V_{BE} = V_0 + v(t) = V_0 + V_m \cdot \sin \omega t$$





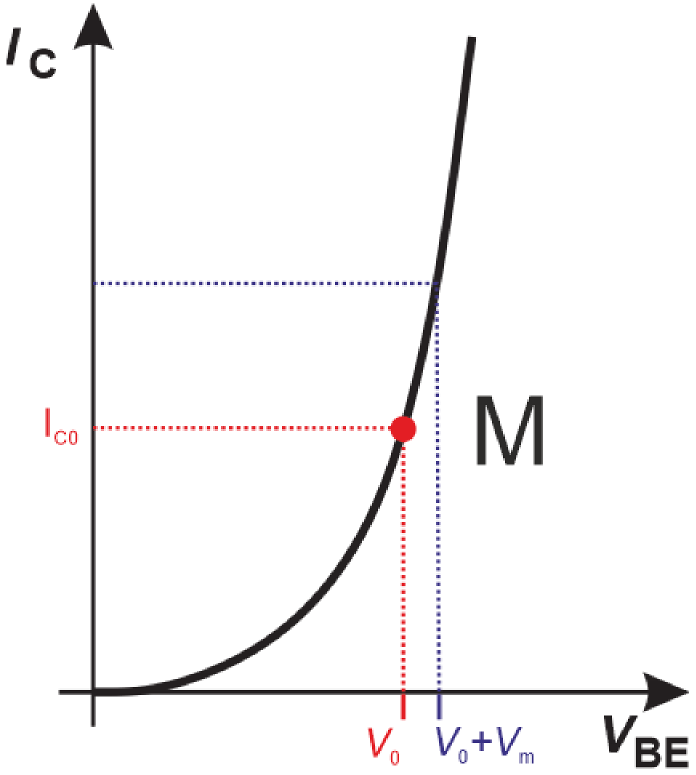
Model bipolarnog tranzistora za male signale

$$I_C = I_S \cdot \left(\exp\left(\frac{V_{BE}}{V_T} \right) - 1 \right) \approx I_S \cdot \exp\left(\frac{V_{BE}}{V_T} \right)$$

$$I_C = I_S \cdot \exp\left(\frac{V_0 + v(t)}{V_T} \right) = I_S \cdot \exp\left(\frac{V_0}{V_T} \right) \cdot \exp\left(\frac{v(t)}{V_T} \right)$$

$$I_C = I_S \cdot \exp\left(\frac{V_0}{V_T} \right) \cdot \exp\left(\frac{V_m \cdot \sin \omega t}{V_T} \right)$$

$$I_C = I_{C0} \cdot \exp\left(\frac{V_m}{V_T} \cdot \sin \omega t \right)$$



Model bipolarnog tranzistora za male signale

- Tejlorov (Taylor) razvoj eksponencijalne funkcije u okolini nule:

$$e^x = \sum_{i=0}^{\infty} \frac{x^i}{i!} = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \frac{x^4}{4!} + \ldots$$

- Za male vrednosti argumenta *x*:

$$|x| \ll 1$$

$$e^x \approx 1 + x$$

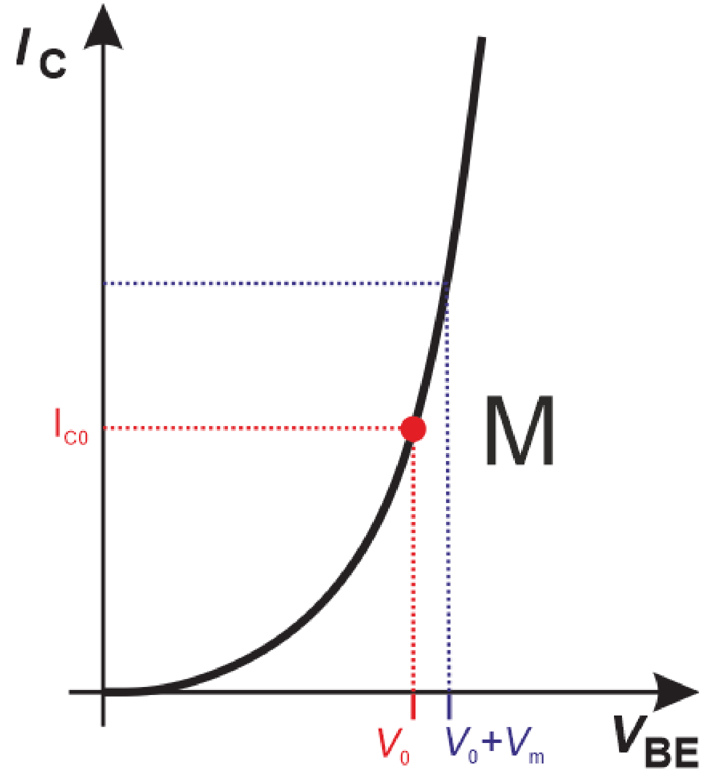
Model bipolarnog tranzistora za male signale

- Sinusna funkcija je manja ili jednaka jedinici, ukoliko je $V_m < V_T$, imamo:

$$I_C = I_{C0} \cdot \exp\left(\frac{V_m}{V_T} \cdot \sin \omega t\right)$$

$$V_m < V_T \quad \Rightarrow \quad I_C \approx I_{C0} \cdot \left(1 + \frac{V_m}{V_T} \cdot \sin \omega t\right)$$

$$I_C = I_{C0} + \frac{I_{C0}}{V_T} \cdot V_m \sin \omega t = I_{C0} + \frac{I_{C0}}{V_T} \cdot v(t)$$



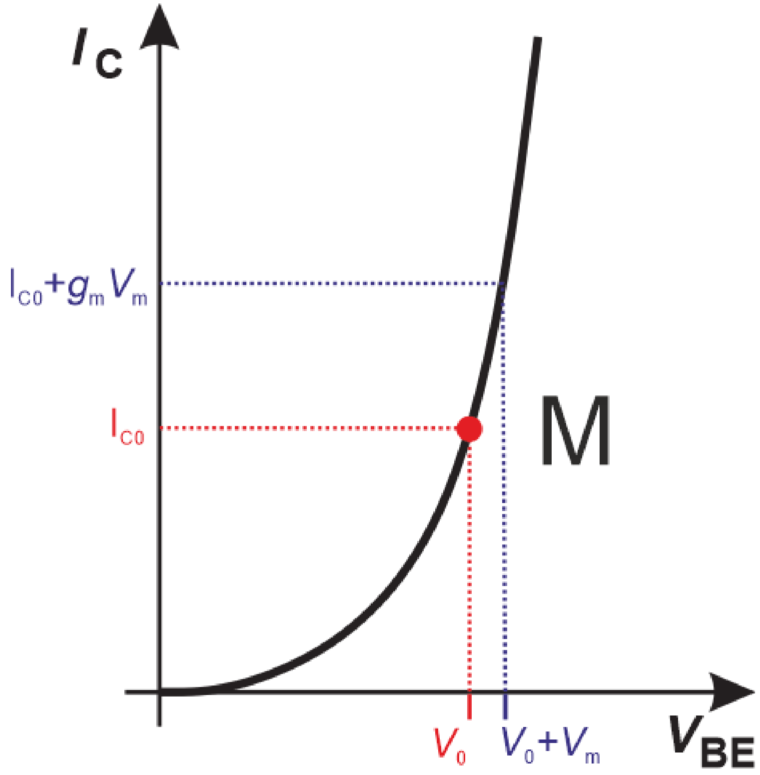
Model bipolarnog tranzistora za male signale

- Količnik kolektorske struje i napona V_T je transkonduktansa tranzistora u radnoj tački M:

$$g_m = \frac{I_{C0}}{V_T}$$

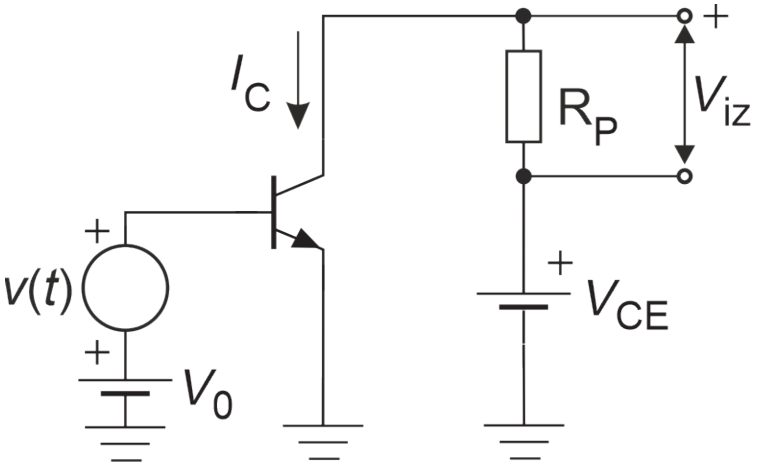
- Kolektorska struja je:

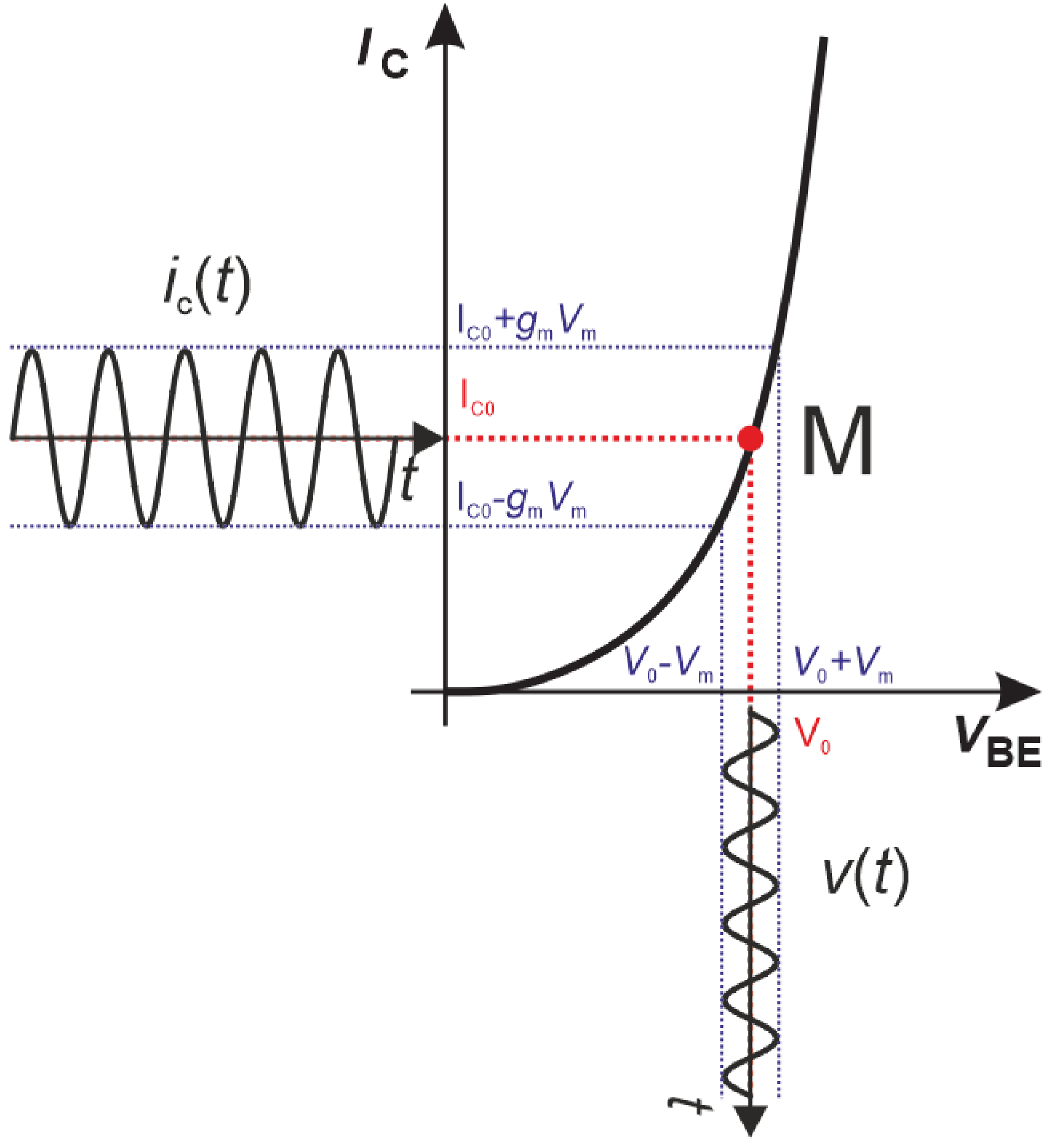
$$I_C = I_{C0} + g_m \cdot V_m \sin \omega t = I_{C0} + \underbrace{g_m \cdot v(t)}_{i_C(t)}$$



Model bipolarnog tranzistora za male signale

$$I_C = I_{C0} + g_m \cdot V_m \sin \omega t = I_{C0} + \underbrace{g_m \cdot v(t)}_{i_C(t)}$$

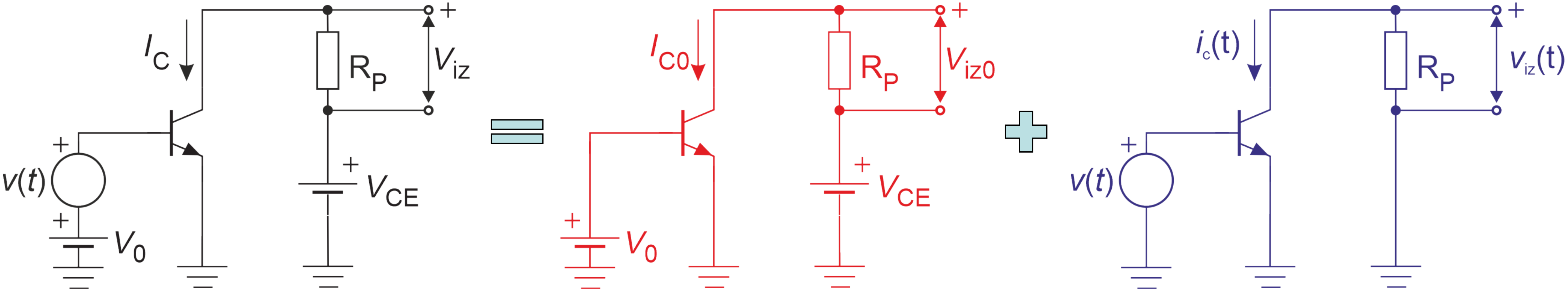




Model bipolarnog tranzistora za male signale

$$I_C = I_{C0} + g_m \cdot V_m \sin \omega t = I_{C0} + \underbrace{g_m \cdot v(t)}_{i_C(t)}$$

Superpozicija

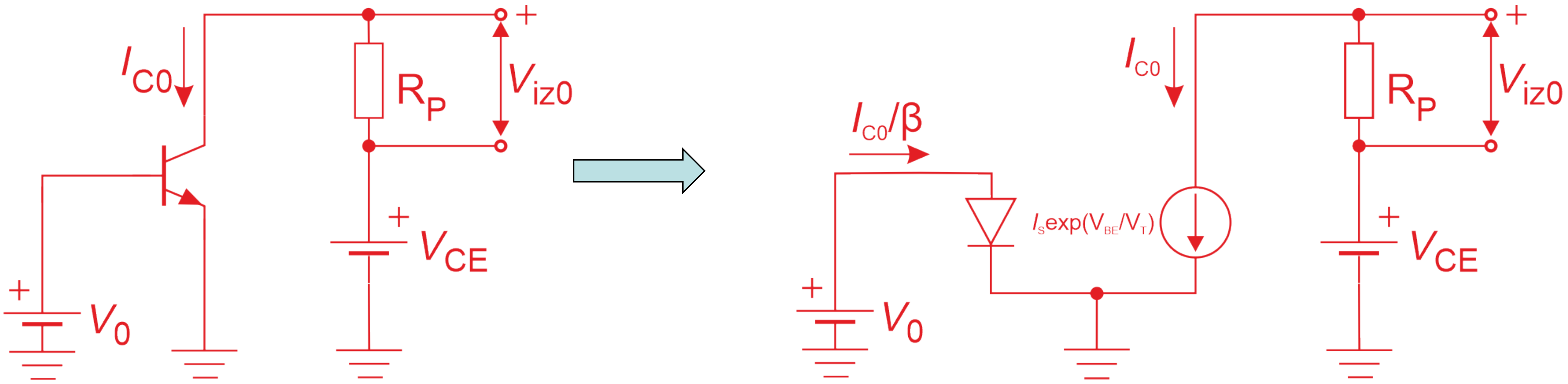


Veliki signali (polarizacija)

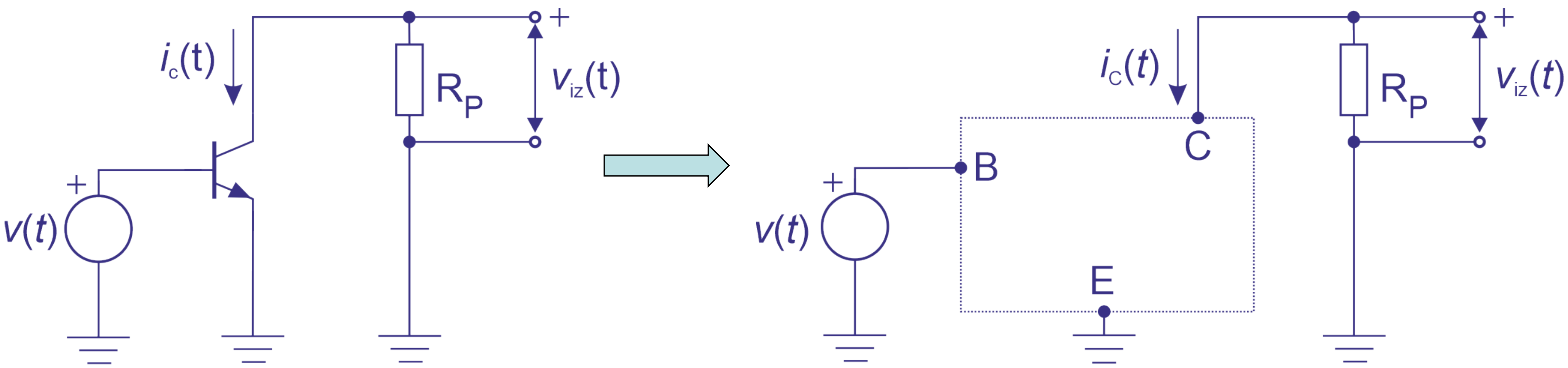
Signali malih amplituda

Model za velike signale

- Model za velike signale – poznati parametri I_S, β.
- Izračunava se I_{C0}.



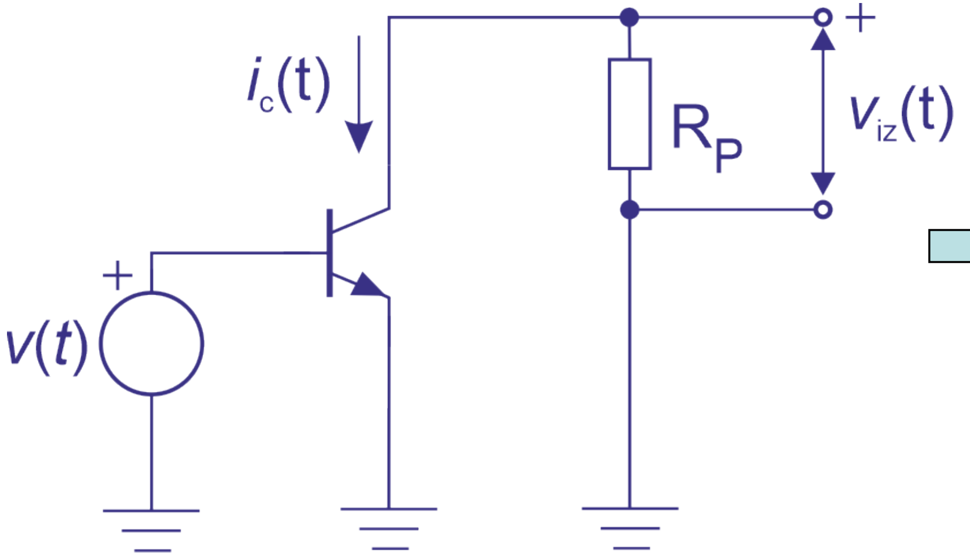
Model za male signale

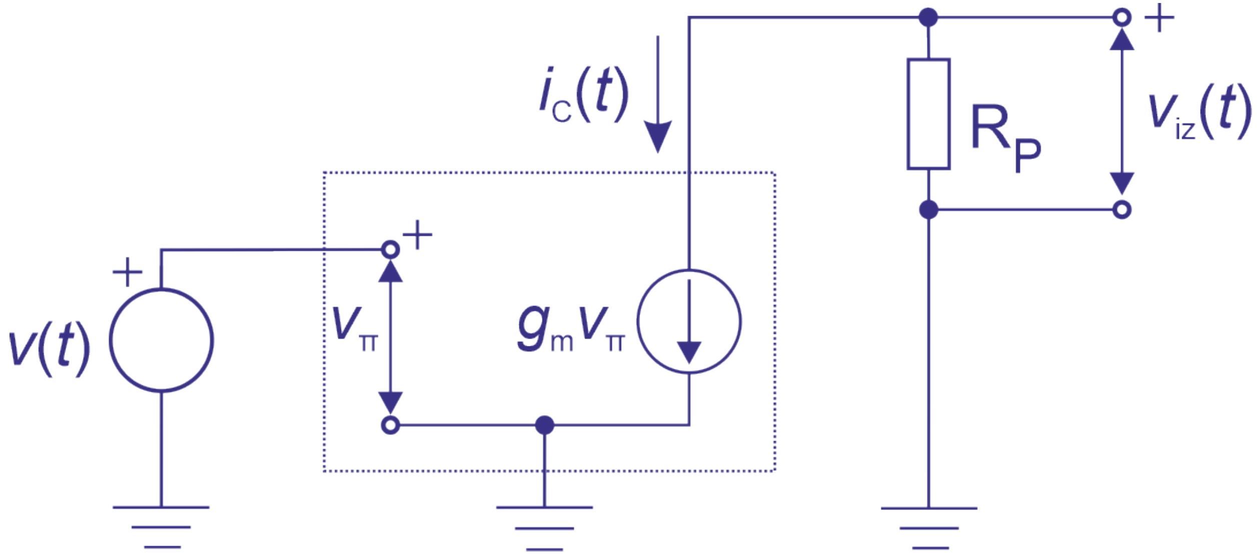


Model za male signale

- Kolektorska struja

$$i_C(t) = g_m \cdot v(t), \quad g_m = \frac{I_{C0}}{V_T}$$

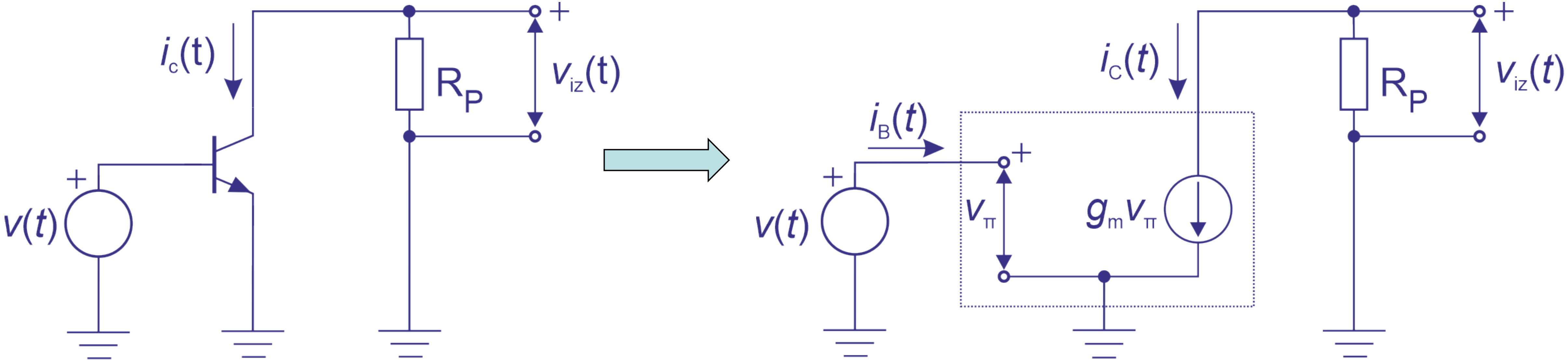




Model za male signale

- Struja baze

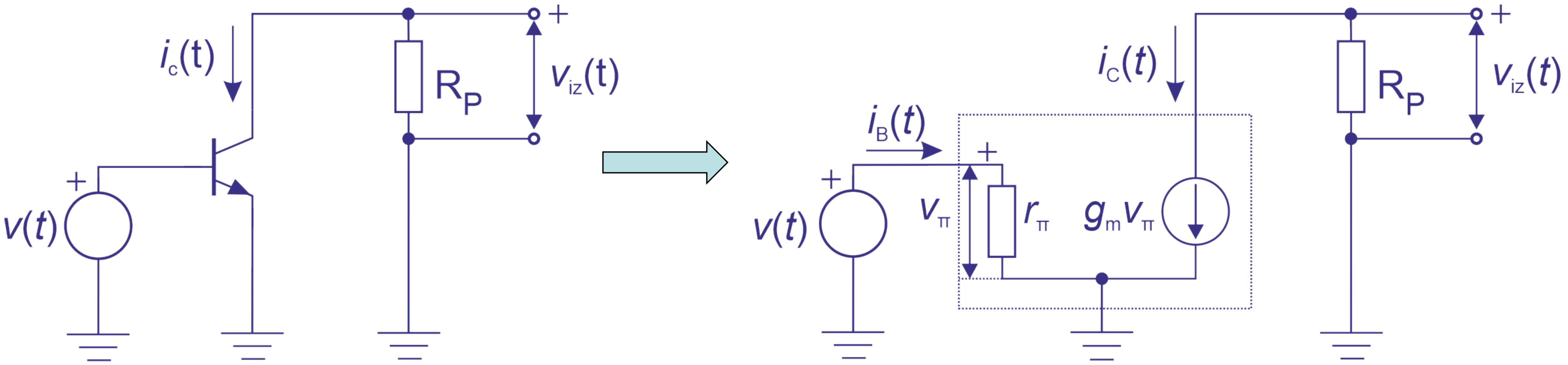
$$i_{\mathrm{B}}(t)=\frac{i_{\mathrm{C}}(t)}{\beta}=\frac{g_{\mathrm{m}}}{\beta}\cdot v_{\pi}, \quad v_{\pi}=\frac{\beta}{g_{\mathrm{m}}}\cdot i_{\mathrm{B}}(t)$$



Model za male signale

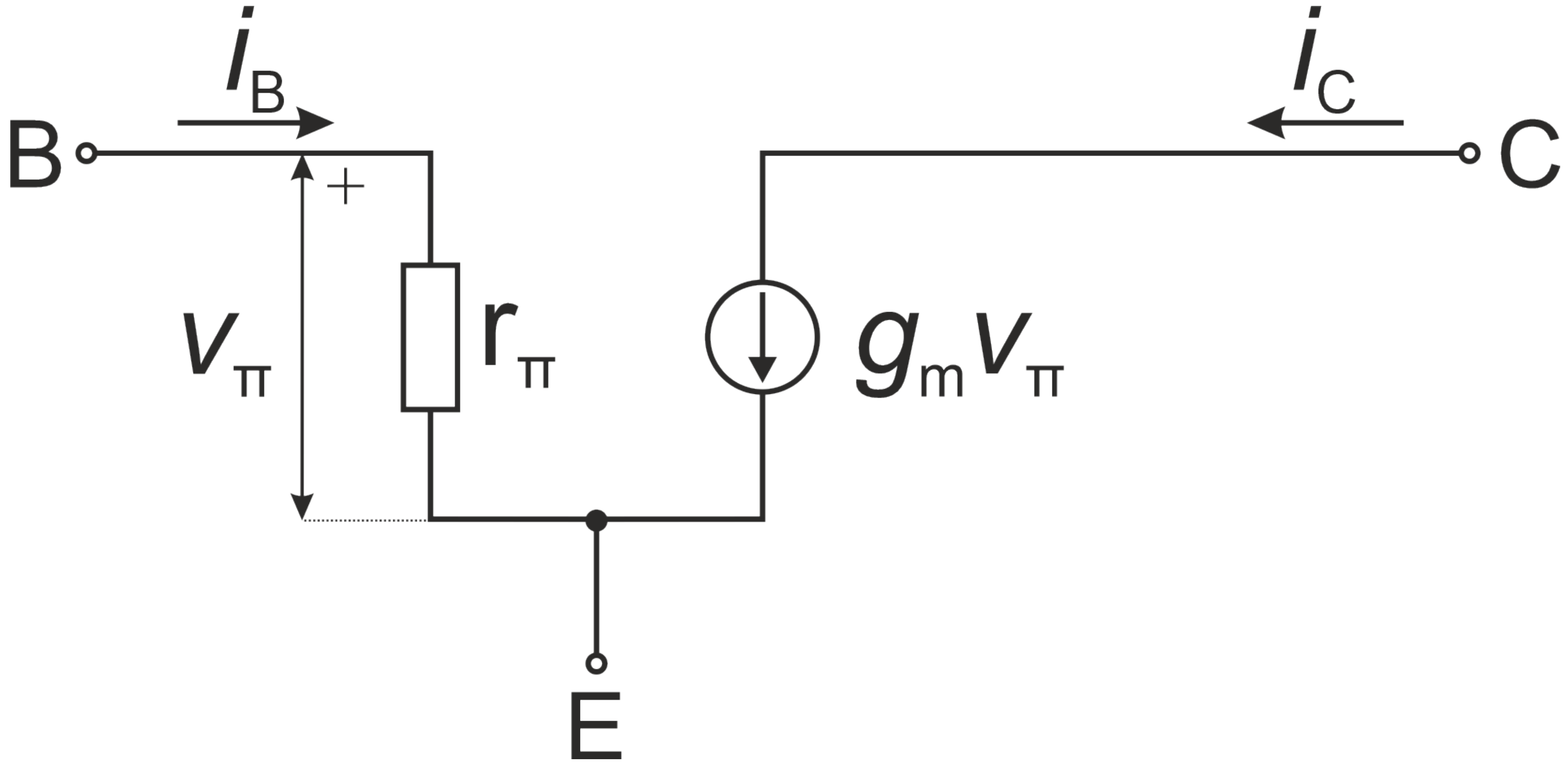
- Otpornost emitorskog spoja

$$v_\pi = r_\pi \cdot i_B(t), \quad r_\pi = \frac{\beta}{g_m}$$



Model za male signale

$$g_{\mathrm{m}} = \frac{I_{\mathrm{C0}}}{V_{\mathrm{T}}}, \quad r_{\pi} = \frac{\beta \cdot V_{\mathrm{T}}}{I_{\mathrm{C0}}}$$



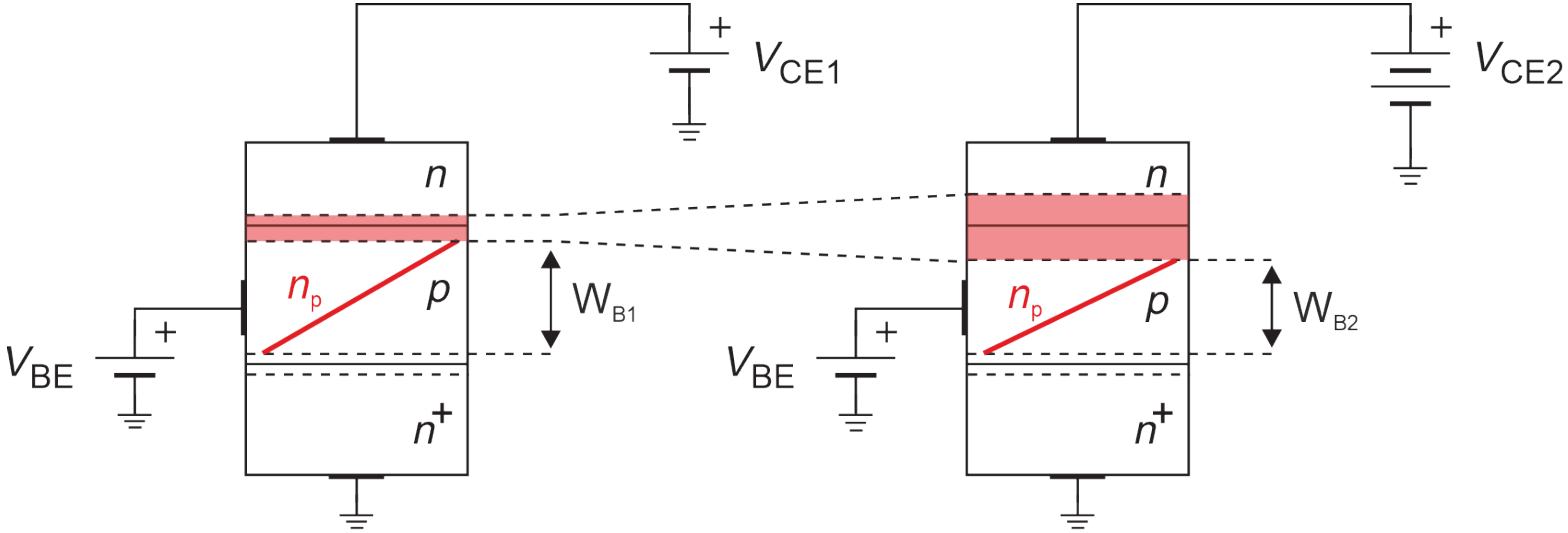
Model za male signale

- Parametri modela za male signale g_m i r_π se izračunavaju na osnovu vrednosti kolektorske struje u jednosmernom režimu, I_{C0}, koja se izračunava primenom modela za velike signale.
- Naponski generatori velikih signala predstavljaju kratak spoj, strujni generatori velikih signala prekid u kolu za male signale.
- Veliki signali se obeležavaju velikim slovima: I_{C0}, V_{BE},… Mali signali se obeležavaju malim slovima i_C, i_B, v_π,…

Erlijev (Early) efekat

- Erlijev efekat, nazvan po J. M. Early-u, je promena efektivne širine baze u bipolarnom tranzistoru usled promene napona između baze i kolektora.
- Veći napon inverzno polarisanog kolektorskog spoja povećava širinu osiromašene oblasti kolektorskog spoja, smanjujući tako širinu baze koja provodi naelektrisanja.

Erlijev (Early) efekat

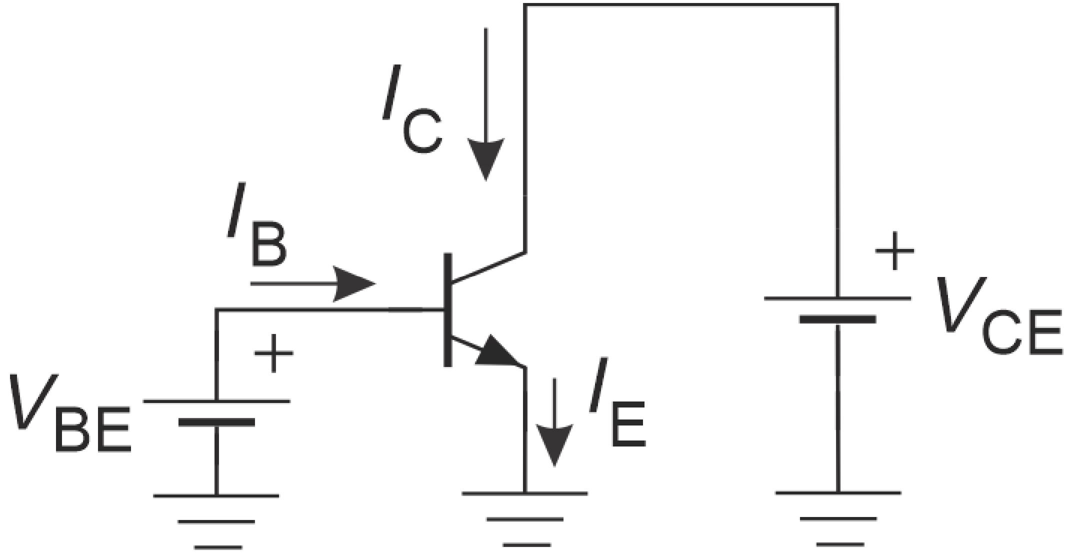


Erlijev (Early) efekat

$$I_C = I_S\left(\exp\left(\frac{V_{BE}}{V_T}\right)-1\right) \approx I_S\cdot\exp\left(\frac{V_{BE}}{V_T}\right)$$

$$I_S = \frac{A_E\cdot q_e\cdot n_i^2\cdot D_n}{W_B\cdot N_B}$$

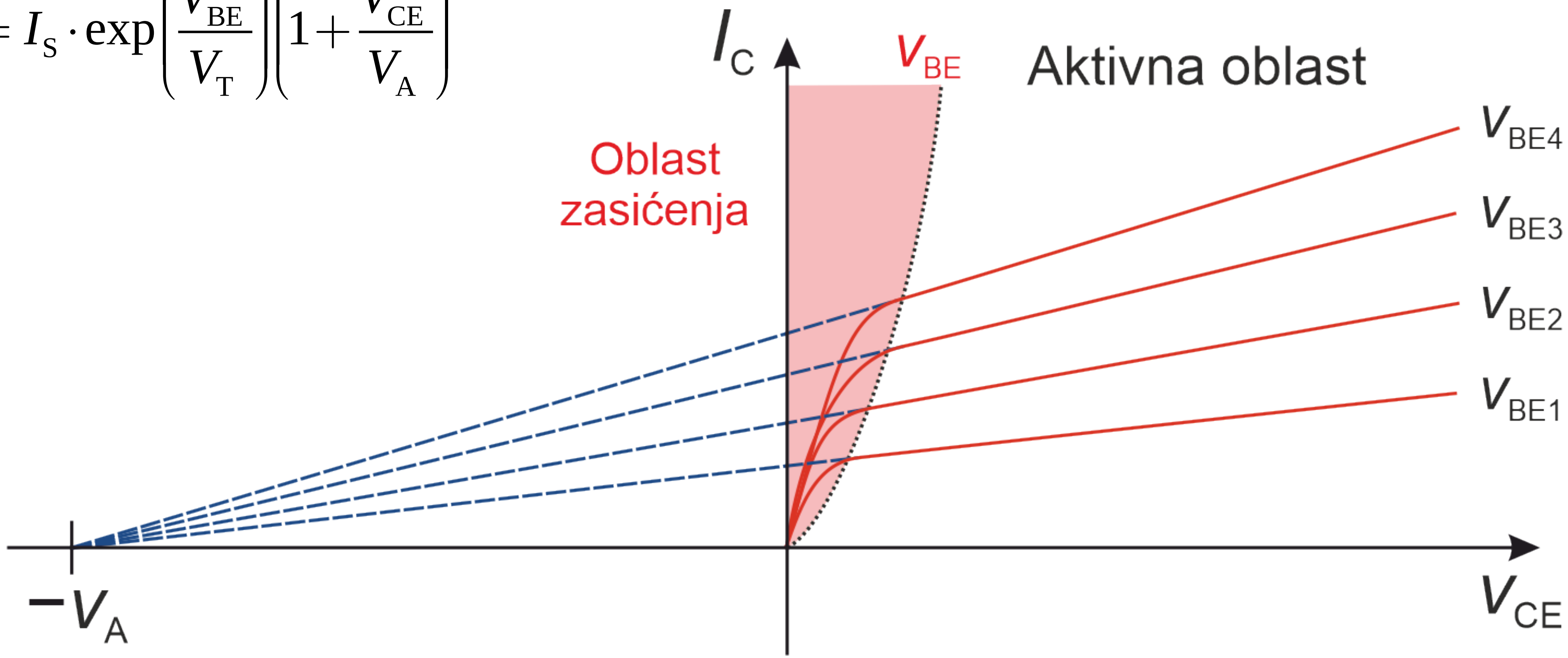
$$W_{B1} > W_{B2} \quad \Rightarrow \quad I_{S1} < I_{S2} \quad \Rightarrow \quad I_{C1} < I_{C2}$$



A_E – površina emitorskog spoja
W_B – širina oblasti baze
N_B – koncentracija akceptora u bazi

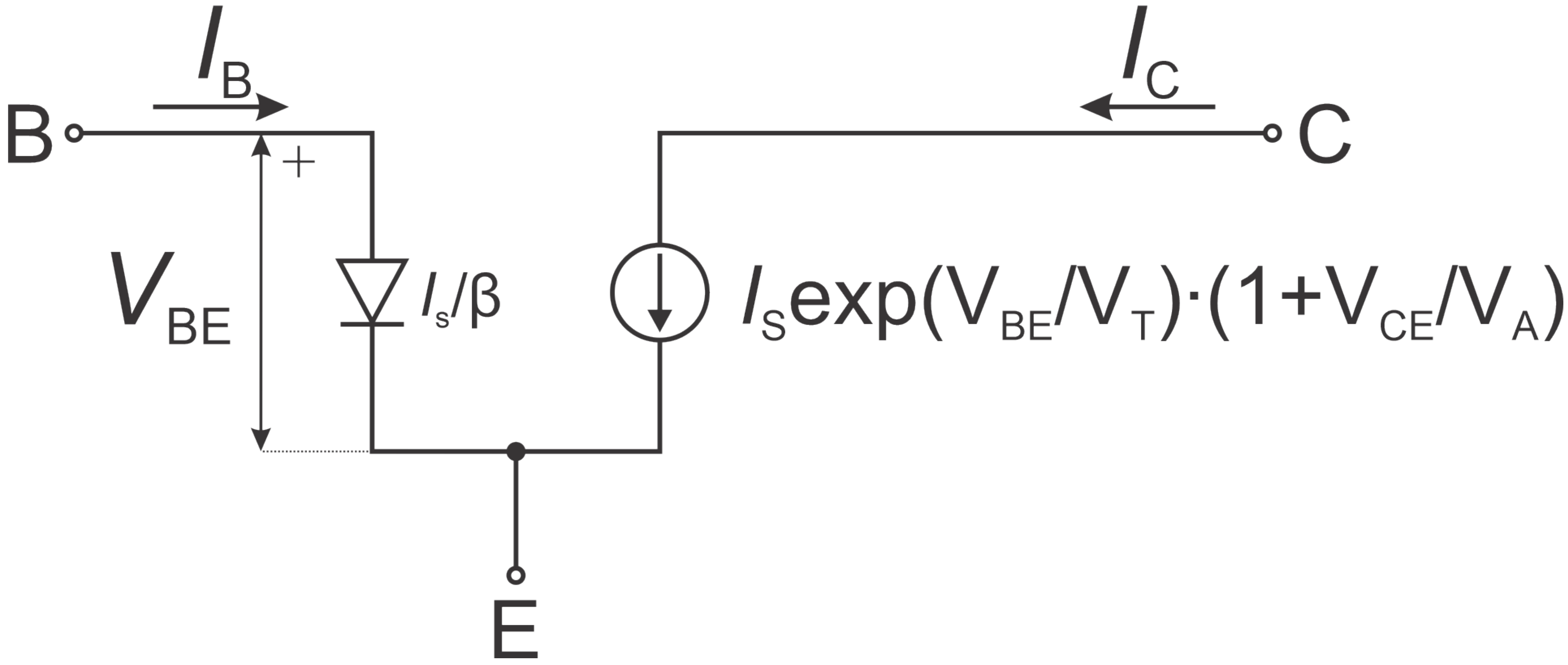
Erlijev (Early) efekat

$$I_C = I_S \cdot \exp\left(\frac{V_{BE}}{V_T}\right)\left(1 + \frac{V_{CE}}{V_A}\right)$$



Erlijev (Early) efekat

- Model za velike signale

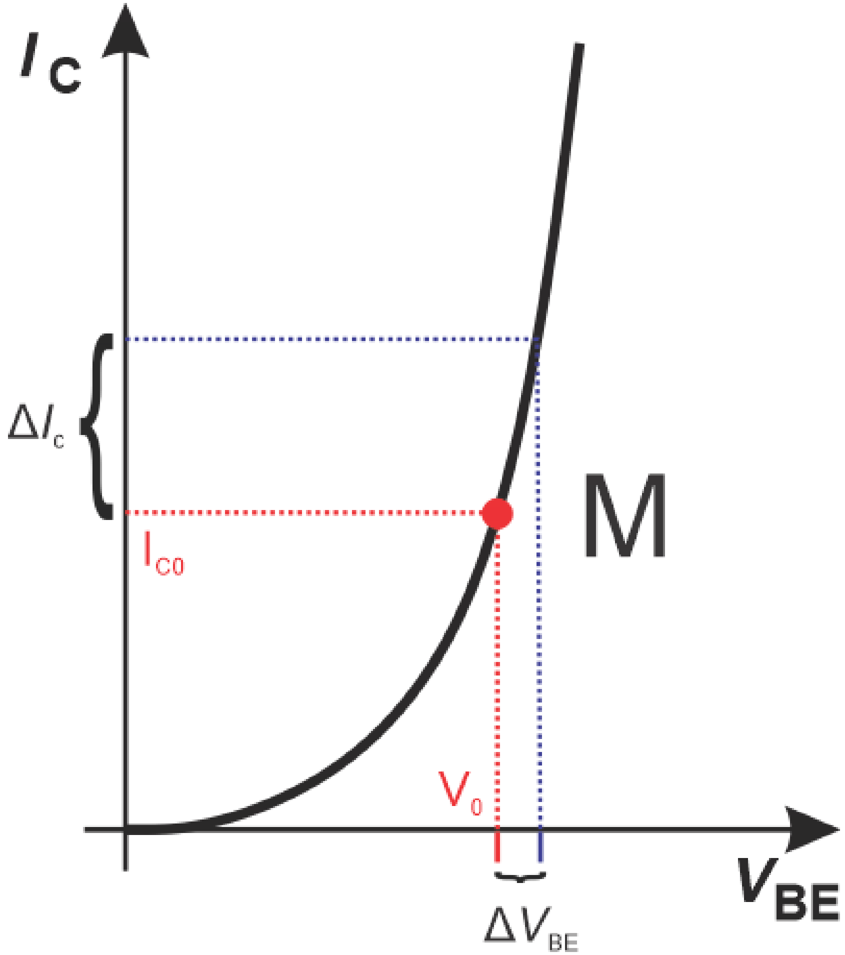


Erlijev (Early) efekat

Model za male signale

- Bipolarni tranzistor je polarisan, postignuta je odgovarajuća radna tačka.
- Prilikom promene napona između dva priključka (V_{CE}), napon na drugim (V_{BE}) ostaje konstantan.
- Modelovanje efekata elementima kola.

Erlijev (Early) efekat



$$I_C = I_S \cdot \exp\left(\frac{V_{BE}}{V_T}\right)\left(1 + \frac{V_{CE}}{V_A}\right)$$

$$g_m = \frac{dI_C}{dV_{BE}}$$

$$g_m = \frac{I_S}{V_T} \cdot \exp\left(\frac{V_{BE}}{V_T}\right) \cdot \left(1 + \frac{V_{CE}}{V_A}\right) = \frac{I_C}{V_T}$$

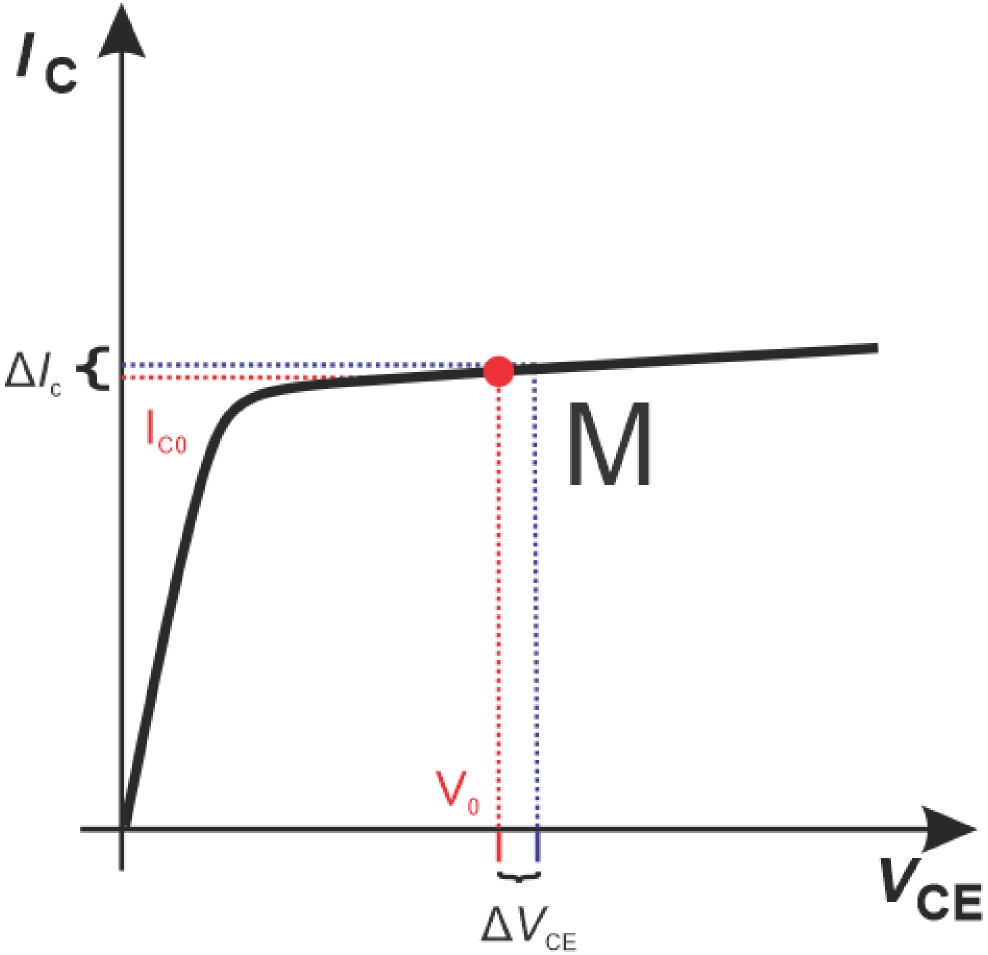
Erlijev (Early) efekat

$$I_B = \frac{I_C}{\beta}$$

$$r_\pi = \frac{\beta}{g_m} = \frac{\beta \cdot V_T}{I_C}$$

- Odnos struja baze i kolektora je nepromenjen, β.

Erlijev (Early) efekat



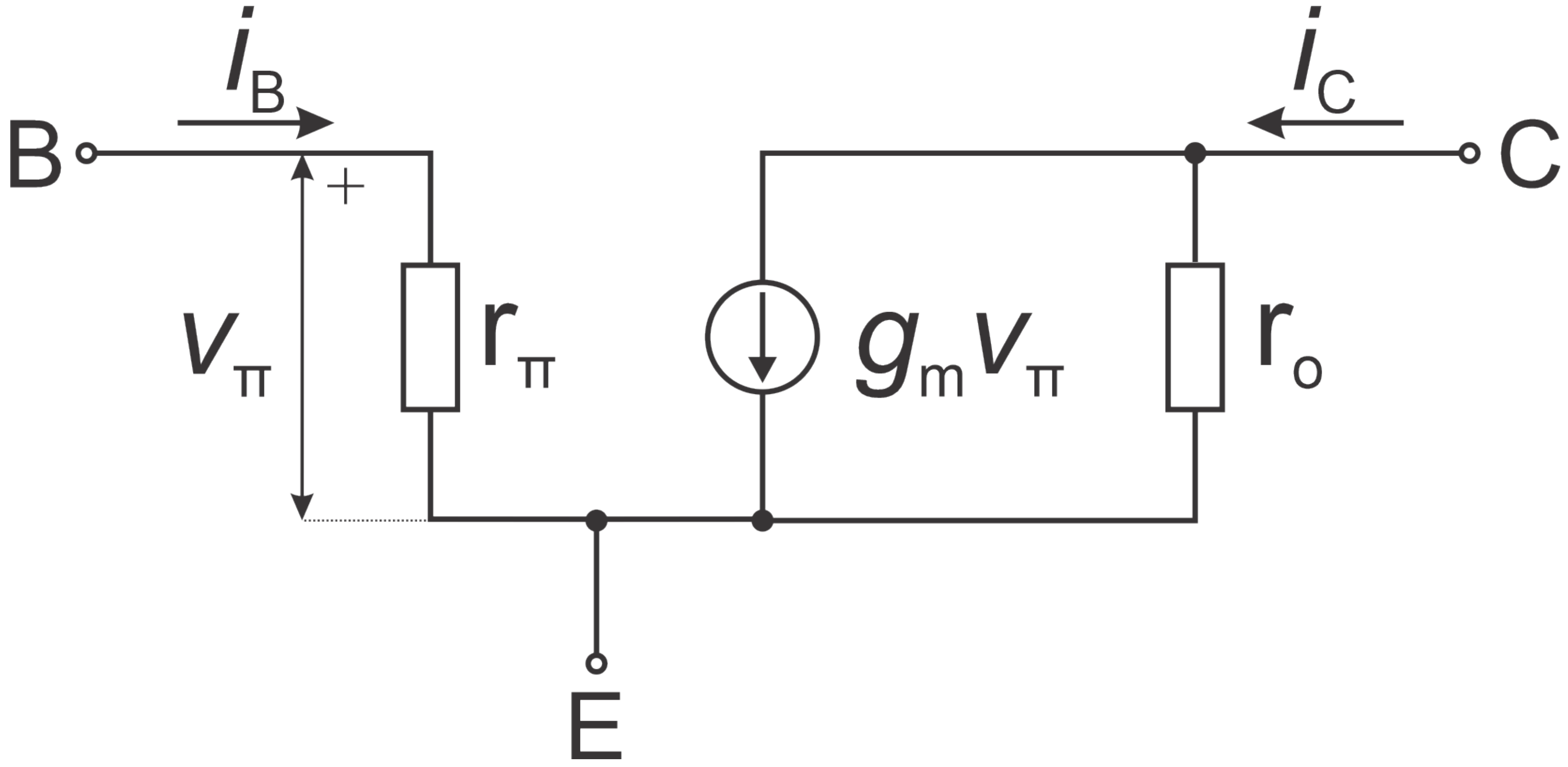
$$I_C = I_S \cdot \exp\left(\frac{V_{BE}}{V_T}\right)\left(1 + \frac{V_{CE}}{V_A}\right)$$

$$\frac{dI_C}{dV_{CE}} = I_S \cdot \exp\left(\frac{V_{BE}}{V_T}\right) \cdot \frac{1}{V_A} \approx \frac{I_C}{V_A}$$

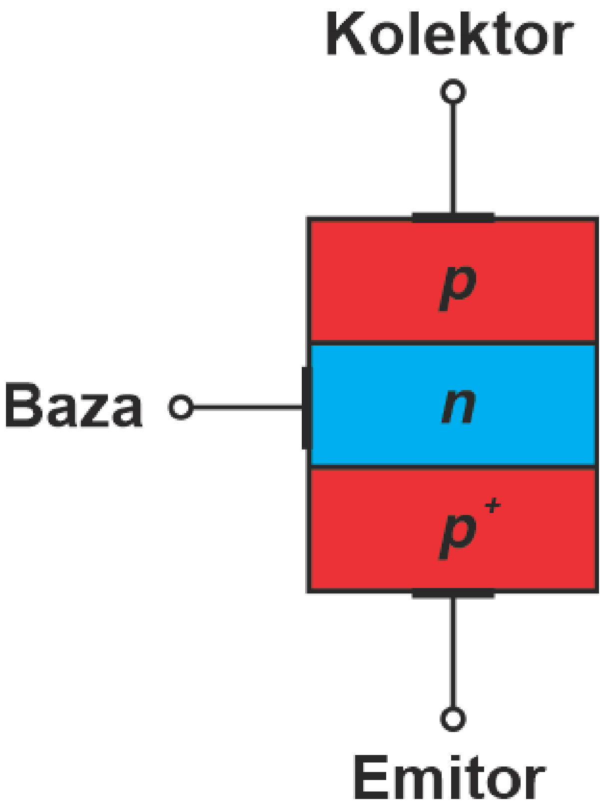
$$r_o = \frac{V_A}{I_C}$$

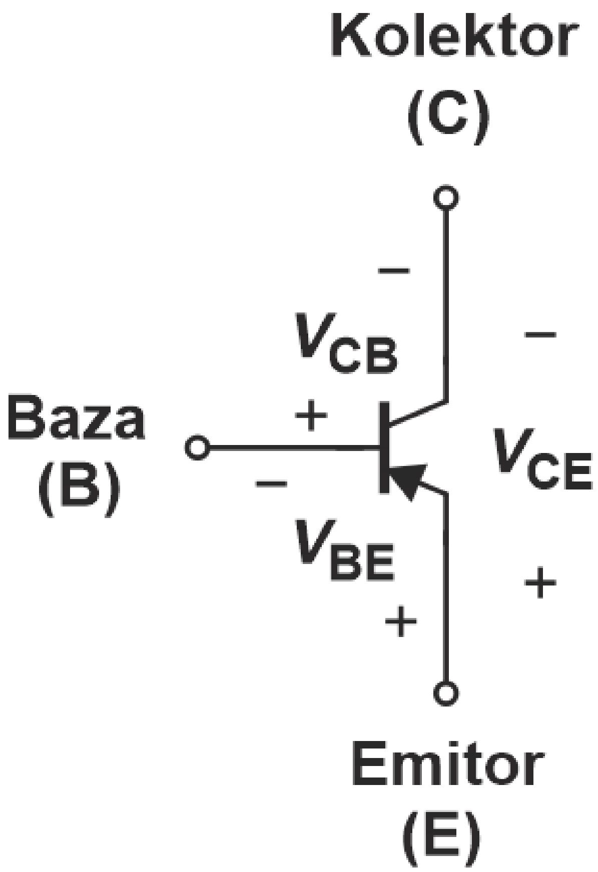
Erlijev (Early) efekt

$$g_{\mathrm{m}} = \frac{I_{\mathrm{C0}}}{V_{\mathrm{T}}}, \quad r_{\pi} = \frac{\beta \cdot V_{\mathrm{T}}}{I_{\mathrm{C0}}}, \quad r_{\mathrm{o}} = \frac{V_{\mathrm{A}}}{I_{\mathrm{C0}}}$$

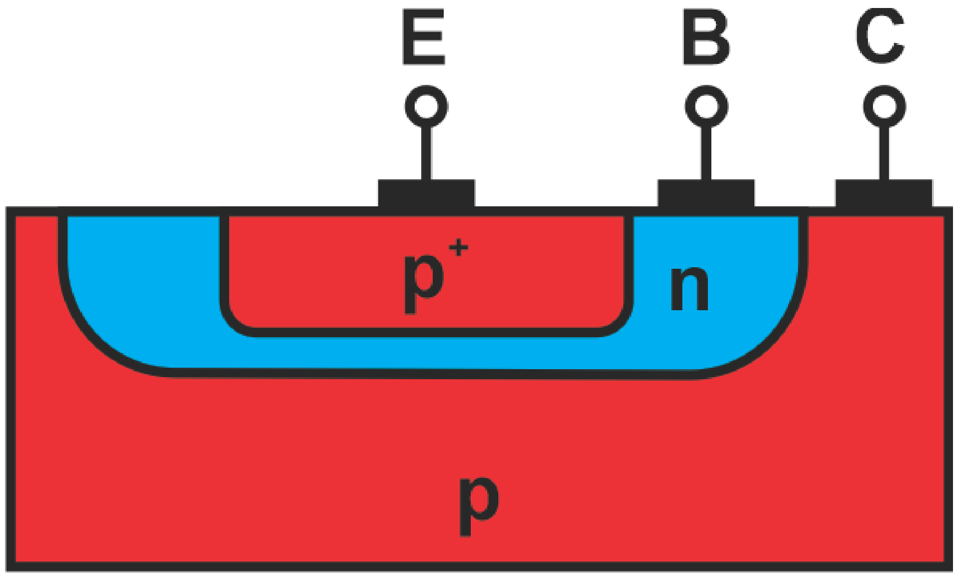


PNP tranzistor





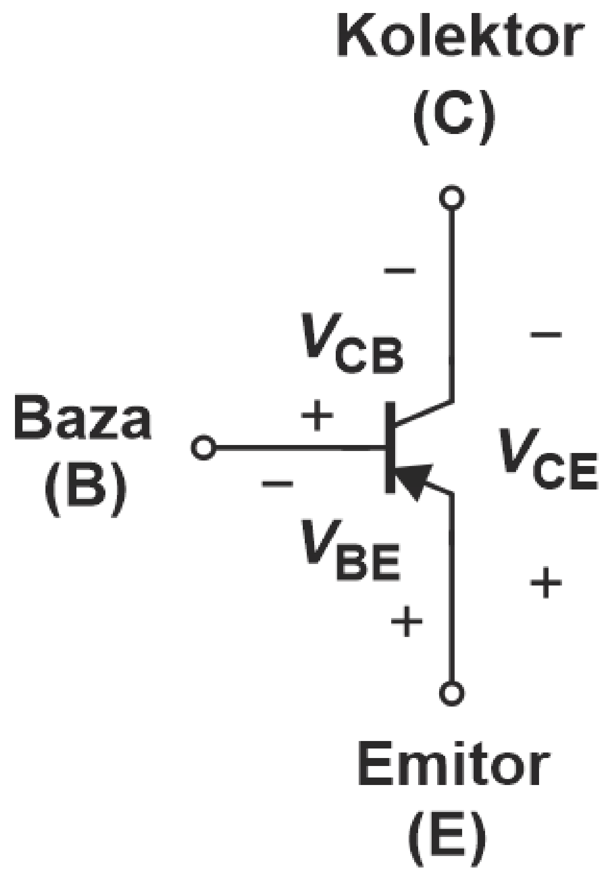
Struktura PNP bipolarnog tranzistora



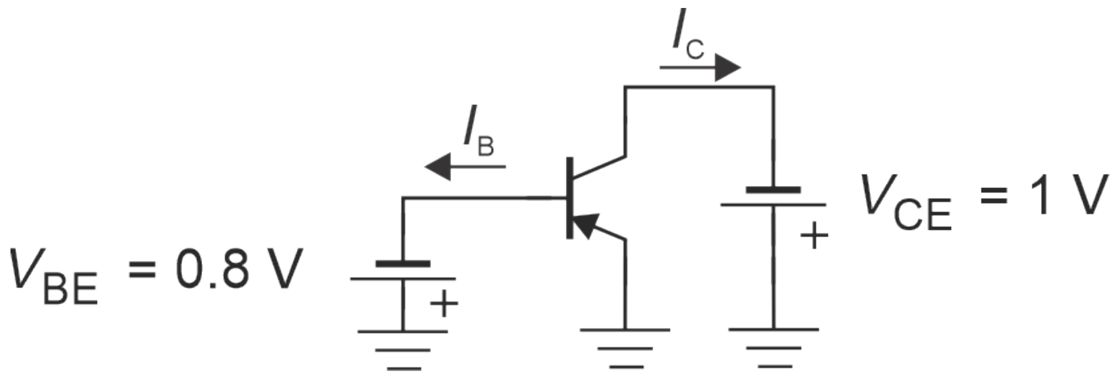
Poprečni presek

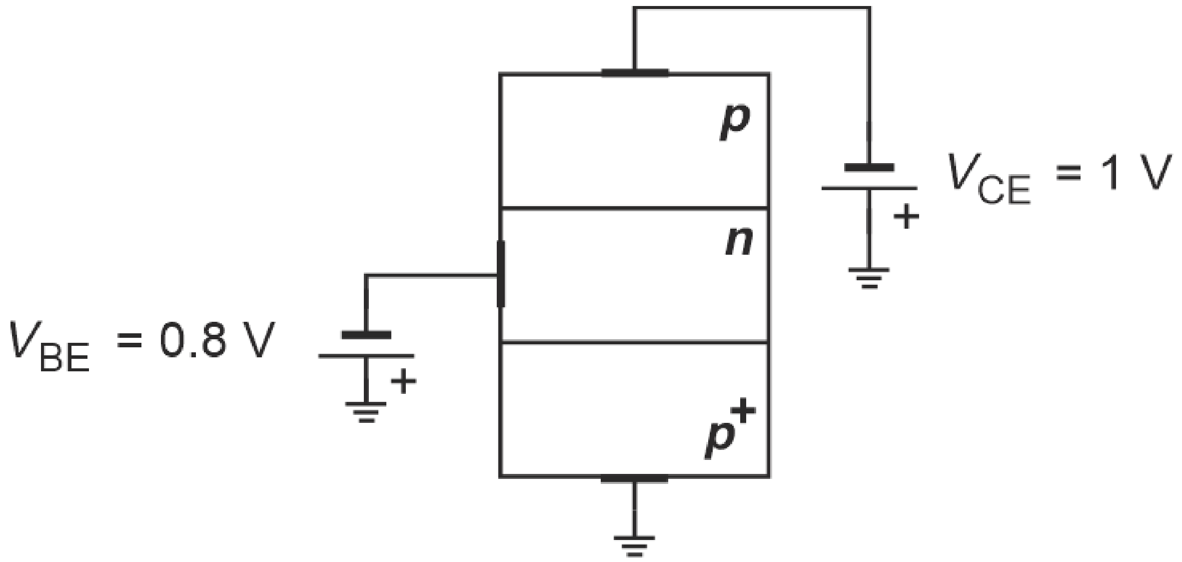
Režimi rada PNP tranzistora

Naponi	Emitorski	Kolektorski	Režim
$V_{BE}<0$, $V_{CB}<0$	direktno	inverzno	aktivna oblast
$V_{BE}<0$, $V_{CB}>0$	direktno	direktno	zasićenje
$V_{BE}>0$, $V_{CB}<0$	inverzno	inverzno	zakočenje
$V_{BE}>0$, $V_{CB}>0$	inverzno	direktno	inverzna aktivna o.



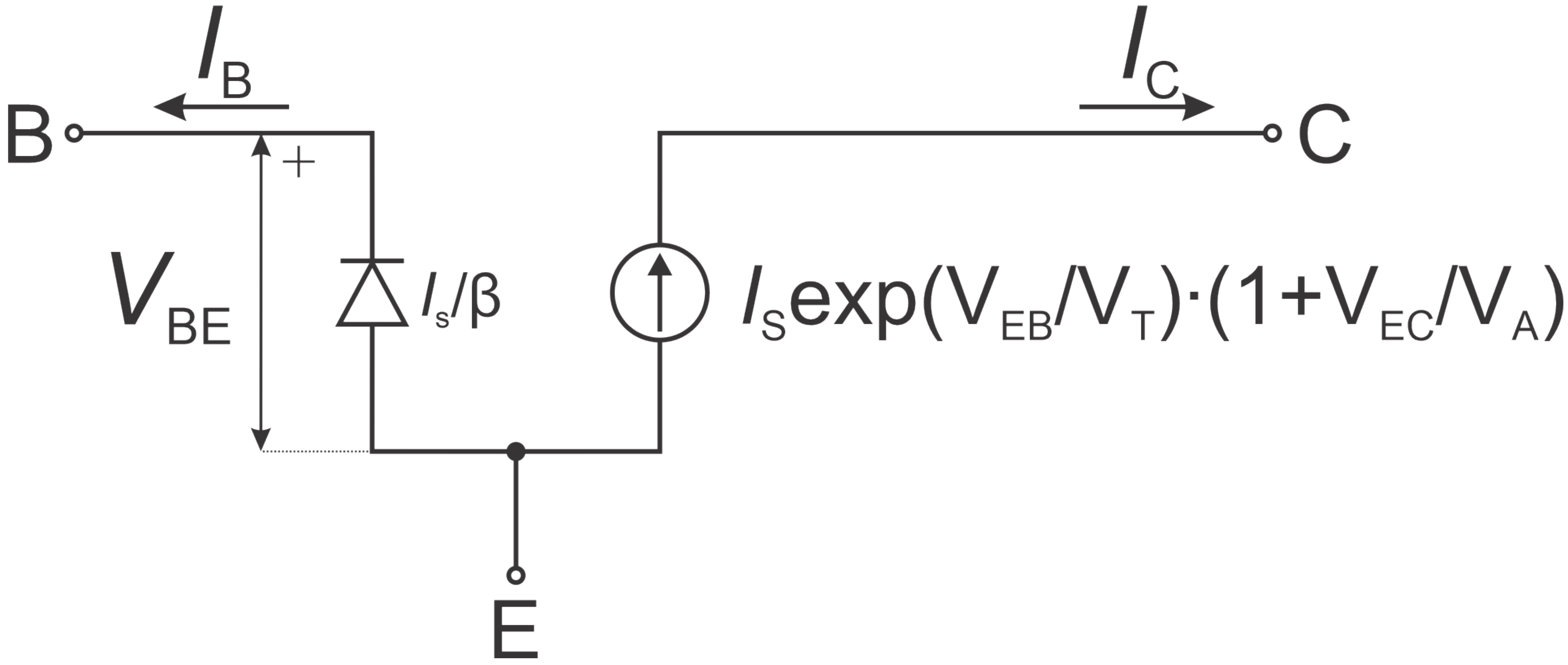
Tranzistorski efekat – aktivan režim





$$V_{CB} = V_{CE} - V_{BE} \leq 0$$

Model za velike signale



Model za male signale

$$g_{\mathrm{m}} = \frac{I_{\mathrm{C0}}}{V_{\mathrm{T}}}, \quad r_{\pi} = \frac{\beta \cdot V_{\mathrm{T}}}{I_{\mathrm{C0}}}, \quad r_{\mathrm{o}} = \frac{V_{\mathrm{A}}}{I_{\mathrm{C0}}}$$